National Aeronautics and Space Administration

TECHNOLOGY INNOVATION

MAGAZINE FOR BUSINESS & TECHNOLOGY

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Upcoming Events

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NASA Centennial Challenges is a program of incentive prizes intended to generate novel solutions to problems of interest to NASA and the nation. The program seeks innovations from diverse and non-traditional sources and the challenges are open to a variety of competitors including private companies, student teams, and independent inventors. Teams from across the country have participated in competitions. Since the program's inception in 2005, notable challenge prizes awarded include: Astronaut Glove Challenge, the Power Beaming Challenge, and the Lunar Lander Challenge. In Fall 2011, NASA plans to hold the Green Flight Challenge. The Centennial Challenge program results have proven that initial failures can produce success, and that innovation comes from many diverse and unexpected sources. In addition to six current Challenges, new Centennial Challenges are on the horizon as NASA seeks ideas from the public and its technical workforce. For information about the CC schedule of events, visit **http://www.nasa.gov/challenges**

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PURSE: $1,100,000

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Managed by: Spaceward Foundation

http://www.spaceward.org

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Worcester, MA

PURSE: $1,500,000

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Managed by Worcester Polytechnic Institute

http://wp.wpi.edu/challenge/

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Location TBA

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Coming in 2012: Nano-Satellite Launch Challenge

Location TBA

PURSE: $2,000,000

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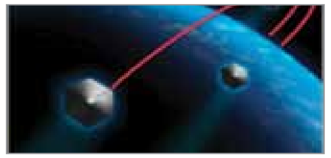

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Seeking visionaries whose world-class ideas, technologies or programs show great promise for making tangible impacts on society.

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For more information please see page 7 or visit http://www.launch.org

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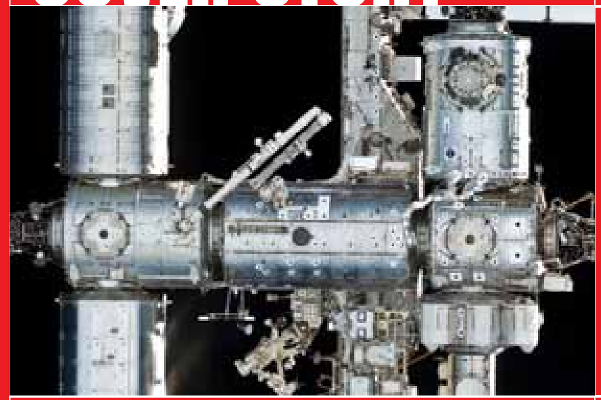
COVER STORY



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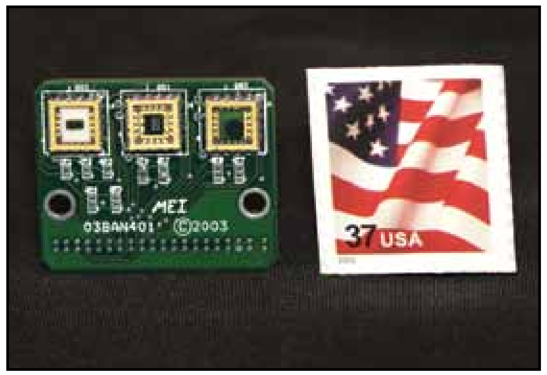

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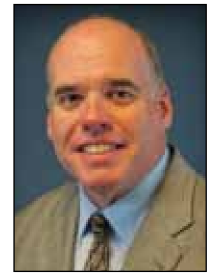
A Message from NASA

UPFRONT with... Joseph C. Parrish

Deputy Chief Technologist, NASA



NASA's future aeronautics, science and exploration missions are grand in scope and bold in stature. America is the nation we are today because of the technological investments made in the 1960s, because of the engineers and scientists of that generation and those policy makers who had the wisdom and foresight to make the investments required for our country to emerge as a global technological leader.

By investing in high payoff, transformative technology that industry cannot tackle today, NASA's Space Technology investments mature the technologies required for NASA's future missions while proving the capabilities and lowering the cost of other government agencies and commercial space activities. Through Space Technology, NASA plans to invest in innovation across the NASA Centers, America's small and large businesses and its universities. There is no shortage of technological innovators in this country; we simply need to invest in them.

An important theme reflected in the President's budget request for NASA is the enhanced use of the International Space Station for technology research, development and testing. In this issue of *Technology Innovation* you will learn about the tremendous amount of R&D that has taken place on the space station over the past decade, much of it occurring within the U.S. portion of the station, now designated a national laboratory.

This research, which took place even as the station was being constructed, includes work conducted not only by NASA, but by industry, academia and other government agencies as well. With the station now completely assembled, we move into a new phase of utilization. Research and testing opportunities onboard the ISS will dramatically increase over this next decade, as this national laboratory begins to fulfill its original mission – serving as a unique testbed for research, innovation and development in a microgravity environment. Like the International Space Station, NASA's Space Technology offers a bounty of research opportunities for business, academia and government agencies, with 10 technology development programs that provide an infusion path to advance the most innovative ideas from concept to flight.

NASA's technology investments also make a difference in our lives everyday here on Earth. Knowledge provided by weather and navigational spacecraft, efficiency improvements in both ground and air transportation, super computers, solar- and wind-generated energy, the cameras found in many of today's cell phones, improved biomedical applications including advanced medical imaging and even more nutritious infant formula, as well as the protective gear that keeps our military, firefighters and police safe, have all benefitted from our nation's investments in aerospace technology. By investing in Space Technology, NASA will continue to make a difference in the world around us.

As you read about the wonders taking place now on world's orbiting laboratory – the International Space Station – dare to dream about where these opportunities will take us over the next 10 or 25 years. The possibilities are limitless!

News Briefs

Chief Technologist Leaves Agency

Dr. Robert D. "Bobby" Braun, who served as the first NASA chief technologist in a decade, left the Agency in October to return to the faculty of the Georgia Institute of Technology in Atlanta. Braun's service at NASA was possible through a two-year intergovernmental personnel agreement with Georgia Tech. Joseph C. Parrish, the deputy chief technologist, is serving as acting NASA chief technologist.

During his tenure at NASA, Braun served as the Agency's principal advisor and advocate on matters concerning Agency-wide technology policy and programs. He also was responsible for the formulation and initial implementation of NASA's Space Technology Program, which develops crosscutting technologies and advanced capabilities to enable NASA's future space missions.

"When I asked Bobby to join the NASA leadership team and establish the new Office of the Chief Technologist, I had to pull him away from his family and his work as a professor and researcher at Georgia Tech," NASA Administrator Charles Bolden said. "Bobby has rebuilt our basic and applied research capabilities, created technology programs to enable our Agency's future success, and clearly articulated the importance of NASA's technology investments as an integral component of our nation's space policy. He's done an incredible job, and we're indebted to him for his exemplary public service."

In his resignation letter to Bolden, Braun stated: "I want to express my gratitude and admiration to the people who came from across NASA as well as external to the Agency to work with me in forming the Office of the Chief Technologist, an organization that had not existed at NASA in a decade, and now reaches into all 10 NASA centers, providing the foundational, crosscutting advances required for the NASA mission directorates. In short order, this team formulated and initiated implementation of the 10 Space Technology programs, integrating and accelerating existing Agency high-priority technology activities within programs designed to engage innovators across the nation.

"Under the leadership of the Deputy Chief Technologist Joe Parrish, and the Space Technology Programs Director, Mike Gazarik, I am confident that these activities and this growing team will continue to serve the Agency well, providing critical capabilities required for our future missions in aeronautics, science and exploration." ■

Parrish Becomes Acting Chief Technologist

Joseph C. Parrish, deputy chief technologist in NASA's Office of the Chief Technologist (OCT), has been named acting chief technologist.

Parrish joined the OCT in January 2011, having come from the Jet Propulsion Laboratory (JPL) in Pasadena, Calif., where he was responsible for technology assessment and mission architecture planning for future robotic missions to Mars. His career has focused on advanced technology development for challenging missions in aeronautics and spaceflight. Before joining JPL, Parrish was the president of Payload Systems Inc. and the vice president for research and development at Aurora Flight Sciences Corp., two small businesses in Cambridge, Mass., that provide aerospace technology development and implementation services to academia, government and industry.

Prior to his time in industry, Parrish was NASA's robotic systems architect for the International Space Station program; led the development of Ranger, a spacecraft servicing telerobot; and served as the NASA program executive for several solar system exploration missions to Mars and beyond, including the Mars Science Laboratory, Mars Scouts, and the Mars Sample Return Mission.

Parrish has received numerous honors, including the Massachusetts Institute of Technology (MIT) Luis de Florez Prize, several NASA Group Achievement awards, the NASA Exceptional Performance Award, and the NASA Exceptional Service Medal. He holds degrees in aeronautics and astronautics from MIT. ■

OCT Appoints New STP Director

Dr. Michael Gazarik has been named director of NASA's Space Technology Program (STP) within the Office of the Chief Technologist (OCT) at NASA Headquarters in Washington D.C.

Until recently, Gazarik served as the deputy chief technologist, focusing on enabling effective implementation of the STP. Prior to his appointment, Gazarik was the deputy director for Programs in the Engineering Directorate at NASA's Langley Research Center in Hampton, Va. In that role, he balanced the directorate's engineering and fabrication capabilities across projects that ranged from conceptual design to spaceflight operations, focused the directorate's resources to deliver flight hardware for numerous flight programs, and led the formulation of a variety of programs in science and human exploration.

Gazarik also served as the project manager for the Mars Science Laboratory entry, descent, and landing instrumentation project, and led Langley's formulation of two major projects: the Sensor Test for Orion Relative Navigation Risk Mitigation project, developing an advanced laser-based rendezvous and docking sensor system, and the Autonomous Landing and Hazard Avoidance project, developing advanced sensor systems for planetary landings. He was principal investigator for the Space Shuttle Program's Extravehicular Infrared Camera Project and served as Chief Engineer of NASA's Climate Absolute Radiance and Refractivity Observatory.

Before joining NASA, he managed the Geosynchronous Imaging Fourier Transform Spectrometer project at the Massachusetts Institute of Technology's Lincoln Laboratory. He also led the development of the Airborne Sounder Testbed-Interferometer.

Gazarik earned degrees in electrical engineering from University of Pittsburgh and the Georgia Institute of Technology. His awards include NASA's Outstanding Leadership Medal in 2007, and one of the Agency's highest honors – the Silver Snoopy Award – in 2006. He has authored or co-authored more than 20 peer-reviewed publications. ■

For more information about NASA's Office of the Chief Technologist and the Space Technology Program, visit www.nasa.gov/oct.

Please mention that you read about it in Technology Innovation.

Ready, Set, LAUNCH!

If you have big ideas for making tangible impacts on society, it's time to get ready. NASA, the U.S. Agency for International Development, NIKE Inc., and the U.S. Department of State are sponsoring the third in a series of LAUNCH events to identify and support the most promising concepts and innovations, this time focused on energy. Previous LAUNCH topics included water and health.

Ten innovators will be selected to spend two days immersed in coaching and professional support from the LAUNCH Council, a diverse and collaborative world-class body of entrepreneurs, venture capitalists, scientists, engineers, and leaders in government, media, and business. At the event, held November 10-13, the LAUNCH Council will help to guide the chosen innovations forward. Afterward, the LAUNCH Accelerator will provide individual support to each innovator to integrate the recommendations and move the innovations closer to implementation. ■

For more information, please visit www.launch.org.

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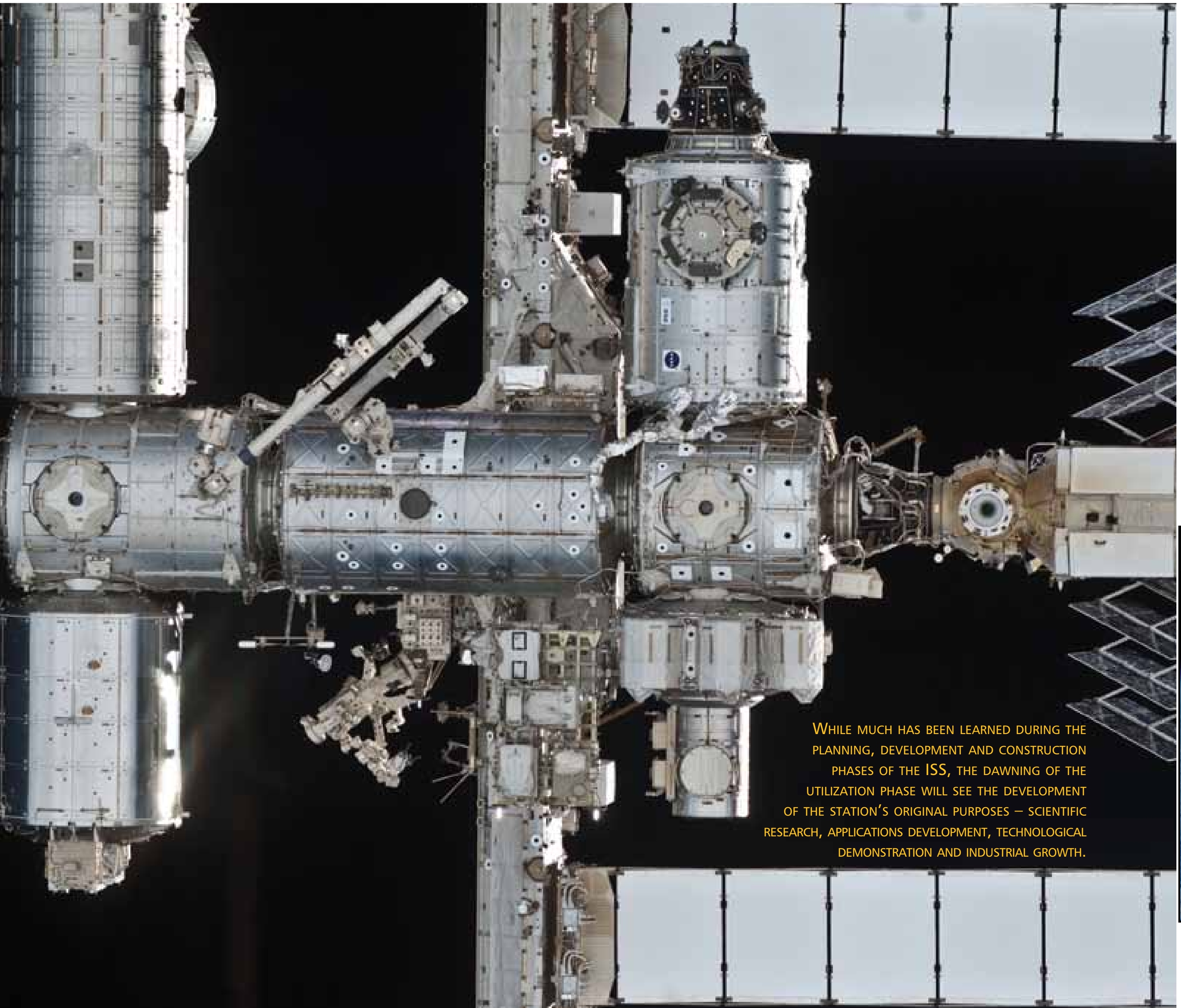
AN ERA OF OPPORTUNITY

The International Space Station Begins Its Next Stage of Partnership and Innovation

By Mark Uhran, NASA Headquarters



While much has been learned during the planning, development and construction phases of the ISS, the dawning of the utilization phase will see the development of the station's original purposes – scientific research, applications development, technological demonstration and industrial growth.

The International Space Station (ISS) is among the greatest of international cooperative endeavors in the history of science and technology. While the design, assembly, and operations of the station to date are remarkable human achievements in their own right, the opening of the utilization era over the next decade presents unprecedented opportunities for partnerships to advance the research and development of space resources.

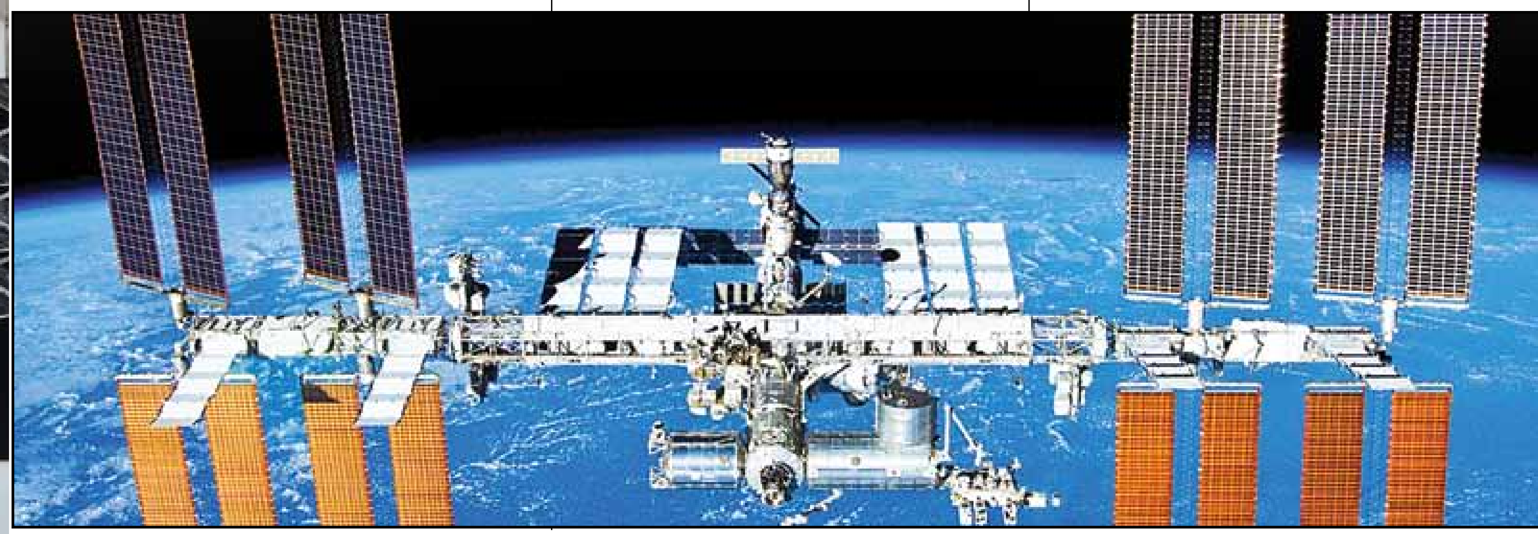
This moment has been a long time coming. Programs conducted over NASA's first 25 years were largely devoted to establishing a foothold in low Earth orbit and on the Moon, so that humans could learn to live and work in extreme space environments. The Mercury, Gemini, Apollo, and Skylab programs brought that goal progressively closer. In 1981, the era of the space shuttle began, and with it came opportunities to deploy the first fully outfitted laboratories for experimentation in microgravity—an environment with the potential for discoveries and technological development not possible on Earth. Spacelab flights enabled by European and Japanese participation—and later U.S. commercial Spacehab flights—resulted in 5–7 days per mission of laboratory-based experiments across a virtually unlimited spectrum of scientific fields.

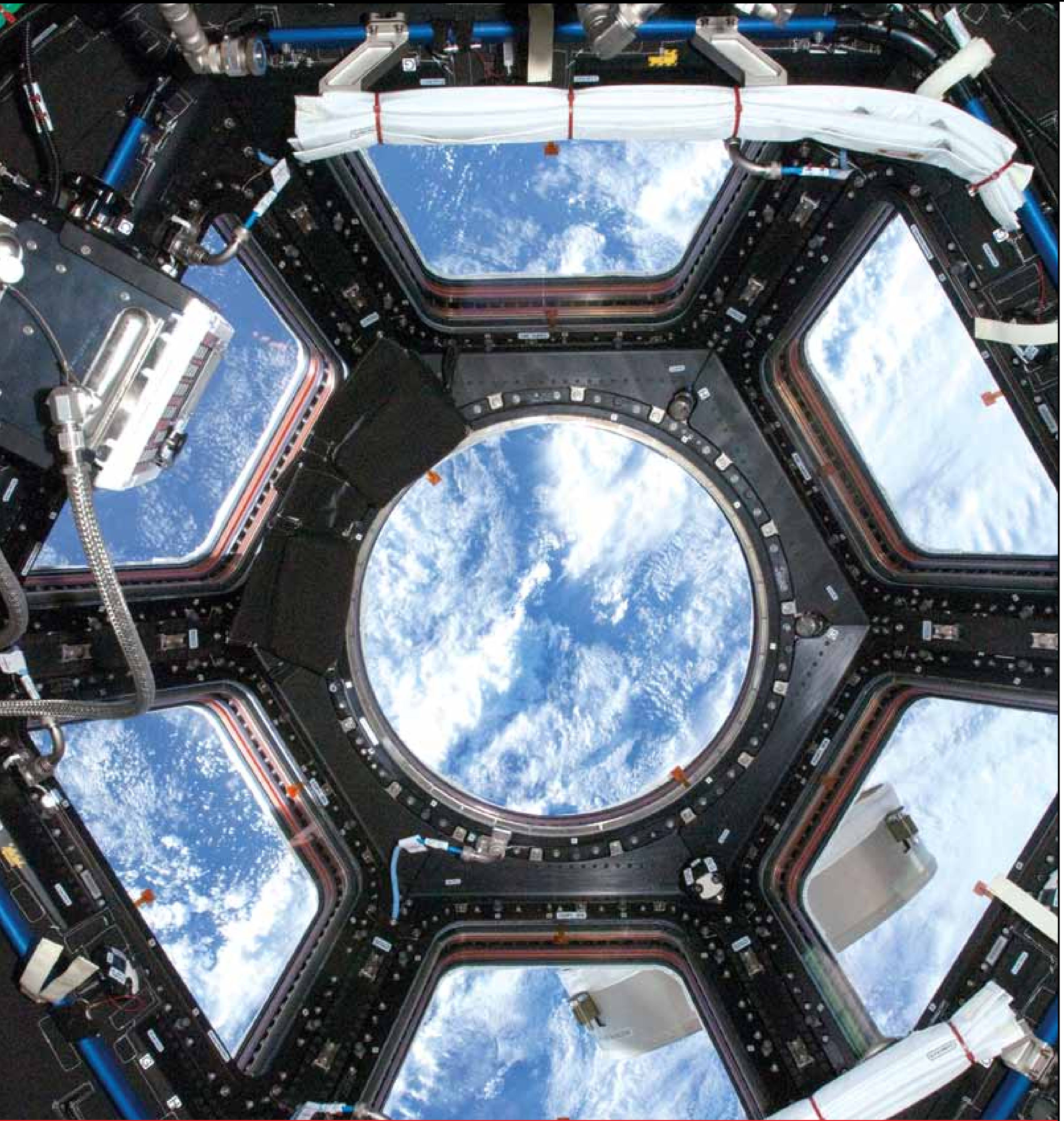
To see how the ISS was assembled, visit:

www.space-video.info/iss/assembly-animation.html

The last 25 years of shuttle-based research could be called a highly effective survey period, setting the stage for—and heralding the potential of—the ISS. During this period, 15 Spacelab and 8 Spacehab pressurized laboratory module missions were flown for a total of approximately 120 days in the microgravity environment. In addition, the Shuttle-Mir program and ISS assembly phase allowed limited opportunities to conduct research on the margins of higher-priority spacecraft operations. However, in sum total, less than 1 year of dedicated laboratory research time was actually accrued over those 25 years. Nonetheless, this period yielded exciting research findings that provide a reliable indicator of the prospects for future scientific and technological payoffs from the completed ISS. This optimism is echoed in the scientific community, noted here by Jeanne Becker, Ph.D., Chief Science Officer for Astrogenetix.

"Space-based research has led to amazing findings, all of which occurred while actively building the ISS," says Dr. Becker, a leader in the field of space-based research. Dr. Becker, who is also on the faculty at Baylor College of Medicine, has a long history of involvement in research conducted on the ISS and space shuttle. Her most recent investigation, delivered to ISS on the final shuttle flight in July 2011, is looking at changes that occur to methicillin-resistant *Staphylococcus aureus* (MRSA) in microgravity, with the goal of creating new vaccines and therapeutics.





A view of the North Atlantic Ocean is visible from the Cupola on the ISS. Built by Thales Alenia Space Italy under contract with the European Space Agency, the Cupola was designed for observation of operations outside the ISS such as robotic activities, the approach of vehicles, and extravehicular activity.

Completing a Vision

With support and guidance from the White House and Congress, NASA is strategically positioning the ISS to best support success as a national research facility and to demonstrate the benefits of international cooperation for peaceful purposes and for improving life on Earth. While much has already been learned technologically, operationally, and scientifically during the assembly of the ISS, the end of this phase will trigger a renewed focus on the original purposes for which the station was designed: scientific research, innovative applications development, technological demonstration, and industrial growth. NASA has been working with international partners in Canada, Europe, Japan, and Russia to maximize the value of this extraordinary global asset. Scientific, technological, and industrial uses are being enabled through new initiatives that are designed to contribute to both the future of space exploration and to the greater benefit of the Nation and world, providing new approaches for improving public health, enhancing energy efficiency, preserving the environment, and stimulating education.

"NASA recognizes the station is an extraordinary asset for the Nation," says NASA Administrator Charles Bolden. "Scientific research and development and education are critical to our national growth and prosperity as a high-technology society. The station offers exceptional opportunities to contribute to this growth."

Completing the ISS as originally envisioned and then operating it as a permanently crewed laboratory, observatory, and test bed has been an enduring controversy. The high cost—approximately $60 billion—and long schedule—approximately 25 years since the conceptual design phase was initiated—has nonetheless yielded an international asset with extraordinary capabilities. Expectations for the ISS will likewise run high for the next decade. In the United States, future policy decisions regarding financial support of human space flight will be strongly influenced by the space station's productivity.

As the ISS assembly era ends and the utilization era begins, the station is strategically positioned for promising opportunities in research and in meeting applications-driven objectives.

Now, following the retirement of the space shuttle, it is time to focus on the promising opportunities the ISS offers. There is no shortage of quality anecdotal evidence that microgravity conditions can reveal important information about the nature of biological and physical systems, and now the ISS is primed for researchers to take advantage of this remarkable facility.

"This is an exciting time, with the National Lab designated for scientific investigations that will return value to the American public," says Dr. Becker. "Investigators across all disciplines now have the opportunity to conduct space-based research. This is the time to use that to the fullest extent."

With NASA's recent selection of the nonprofit Center for the Advancement of Science in Space to manage the U.S. National Laboratory onboard the ISS, the elements necessary to successful partnerships across the U.S. scientific, technological, and industrial communities are falling into place. The ISS is carefully and deliberately being positioned in a manner that will ensure that this U.S. asset will provide maximum value to the Nation for years to come. ■

Mark Uhran is NASA's Assistant Associate Administrator for the International Space Station.

For more information, contact him at mark.l.uhran@nasa.gov, or visit www.nasa.gov/mission_pages/station/main/index.html.

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BIOLOGY IN ORBIT

How Research Partnerships Growing Plants, Cells, and Animals, and Testing New Drugs on the ISS Pays Off on Earth

By Kenneth A. Souza
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NASA Kennedy Space Center
Louis Stodieck, Ph.D.
BioServe Space Technologies
University of Colorado
Kevin Y. Sato, Ph.D.
Lockheed Martin
Richard Mains
Mains Associates Inc.

Astronauts Daniel W. Burch and Franklin R. Chang-Diaz at the Biomass Production System (BPS) on Endeavour's mid deck while returning the BPS to Earth. Developed by Orbital Technologies Corp. with an SBIR award from NASA, the BPS is a habitat for conducting plant research.

The dramatic expansion of biotechnologies over the past few decades has opened exciting new vistas for biology and biomedicine. At the same time, the emerging commercial launch sector and the completed International Space Station (ISS) have the potential to cooperatively accelerate space research and discovery in these areas.

Some questions can only be answered in space. The unique environment of low Earth orbit—microgravity, extreme temperatures, radiation—produces effects difficult to impossible to replicate on Earth. But the conditions of space also offer opportunities for discovery across many fields of study that are unattainable on the ground. Some of the questions that space research promises to unlock are related to space exploration: "How can humans live in space for long periods?" and "How can sustainable food supplies for long-duration missions be developed?" Other questions apply to life on Earth—with an emphasis on "life."

Space biology—the basic, more fundamental mechanisms by which living things adapt to the microgravity of spaceflight—is a developing field with the potential to provide real solutions for improving life in space and on Earth. The dramatic expansion of biotechnologies over the past few decades has opened exciting new vistas for biology and biomedicine. At the same time, the emerging commercial launch sector and the completed space station have the potential to cooperatively accelerate space research and discovery in these areas. Space life scientists are primed to take advantage of new biotechnologies and apply them to new questions being raised that can be answered only in the virtual absence of gravity. New tools such as lab-on-a-chip devices, fluorescent molecular probes, and novel cell culture chambers are all now in the hands of researchers who are conducting unprecedented space-based experiments with potentially significant returns for everything from crop growth to disease treatment and preventative medicine. Also under study is the next generation of habitats for rodents and large plants, which will enable scientists to investigate on the ISS the basic mechanisms of growth, reproduction, and aging, and apply the results to problems associated with human space exploration as well as health issues on our home planet.

As a National Laboratory, the ISS is the prime facility for U.S. space biology research. Through the diligence of the space station's crew and the ingenuity of researchers from within the Agency and among its partners in industry and academia, NASA stands poised to make breakthroughs in the life sciences that may benefit people worldwide while enabling missions to carry humans further out among the planets.

Green (Thumb) Innovation

One of the many challenges NASA faces when planning for long-duration spaceflight is providing sustainable sources of food, water, and air for the astronauts. Biological solutions may offer the key. Human bioregenerative life support and food production will need to take place "locally" in space; this need requires extensive plant growth studies in space as a means for developing these resources.

This objective drove the design and development of the Biomass Production System (BPS) by Orbital Technologies Corporation (ORBITEC) of Madison, Wisconsin, via the NASA Small Business

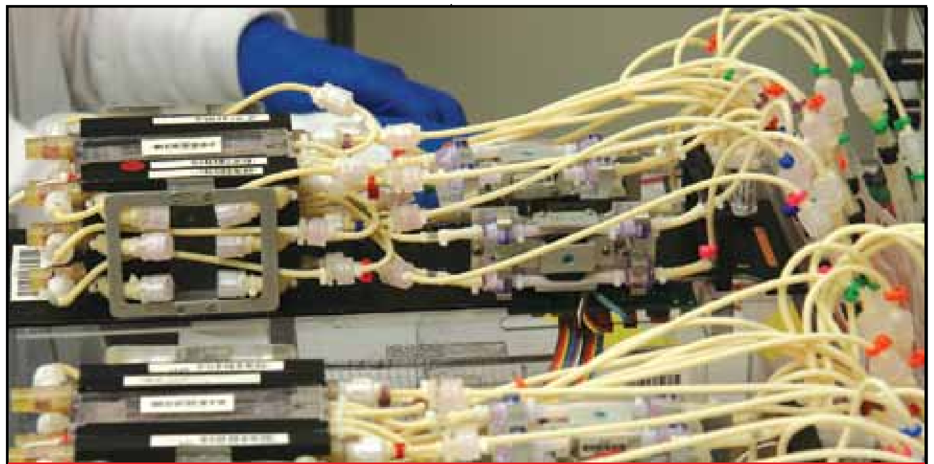
> **The basic, more fundamental mechanisms by which living things adapt to the microgravity of spaceflight - is a developing field with the potential to provide real solutions for improving life in space and on Earth.**

Innovation Research (SBIR) process and a contract with the Ames Research Center.

The BPS is an automated, ISS-compatible plant habitat capable of providing complete environmental control, real-time plant data gathering, crew access for plant harvest or pollination, digital imaging, data storage and downlink, and software control. The system was tested on the ISS for 73 days, using mustard plants and wheat to evaluate the platform. Four independent growth chambers were used, with seeds planted preflight and watered and monitored in flight.

The BPS was highly successful, producing and controlling nearly identical pre-programmed growth environments for the ISS flight unit and the Earth-based control experiment. This is a critical requirement for both growing healthy plants in space and conducting high-quality microgravity research. The seeds in the BPS germinated and mature plants grew. When compared with ground controls, the plants' biological processes and root development were normal in the BPS. This represented a milestone, as previously flown plant chambers showed that roots accumulated only around the water delivery tubes in the root module; in the BPS they spread throughout the soil medium, just as they do on Earth.

One important legacy of the BPS is the system's innovative, fluorescent-based plant lighting system. ORBITEC has continued to refine and optimize the lighting system using different colored LEDs to better simulate natural sunlight conditions during plant growth. ORBITEC is pursuing various commercial applications of this system and other BPS-derived components, including high-efficiency, energy-saving lighting options for agriculture and consumer aquariums.



A Cell Culture Module Rail, loaded with fluid flow path tubing and cell-filled bioreactors (on the left), was used in studies that flew on the ISS in 2010 and that may have significant implications for tissue regeneration and microbial virulence. The studies are a partnership among NASA, the Department of Defense, Walter Reed Army Institute of Research and Tissue Genesis Inc.

The company is collaborating with a team led by Purdue University and including Rutgers University, the University of Arizona, and Michigan State University on a U.S. Department of Agriculture-funded project to improve and evaluate LED lighting for commercial greenhouse use. The LED project's goal is to increase greenhouse yields and decrease energy costs— a major "green" business advantage.

In addition to Ames and ORBITEC, the BPS partnership included Kennedy Space Center and the Dynamac Corporation, based in Rockville, Maryland.

Members of the BPS research team have published several scientific papers as a result of their studies aboard ISS.

Benefits for Soldiers & Astronauts

A growing body of research is showing that spaceflight alters the body's ability to heal wounds and fight off disease. In addition, several species of bacteria have been shown to both become more virulent in microgravity and multiply more quickly than on Earth. To further study these effects of the space environment, Ames Research Center's ISS Research Project Office partnered with the Department of Defense (DoD) Space Test Program, Walter Reed Army Institute of Research (WRAIR), and Tissue Genesis Inc. (TGI) of Honolulu, Hawaii, on two spaceflight cell biology experiments, together called Space Tissue Loss (STL), which flew on the ISS in 2010 and 2011.

In these experiments, the DoD and WRAIR linked their long-term interest in combat casualty care and improved wound healing with basic, NASA-sponsored space biology research in stem-cell-based tissue regeneration and microbial virulence. The knowledge gained at the cell level through these STL studies may prove useful in addressing potential medical situations astronauts encounter in spaceflight, as well as those that soldiers confront on the battlefield. The experiments may also contribute important knowledge in preventative medicine for the greater public. STL experiments were conducted in space using the Cell Culture Module (CCM). The CCM is a locker-sized, automated cell incubator system with commercially available, hollow fiber bioreactors. A cell culture medium flows through the hollow fibers delivering nutrients and removing waste while enabling cells to grow protected from potentially damaging forces.

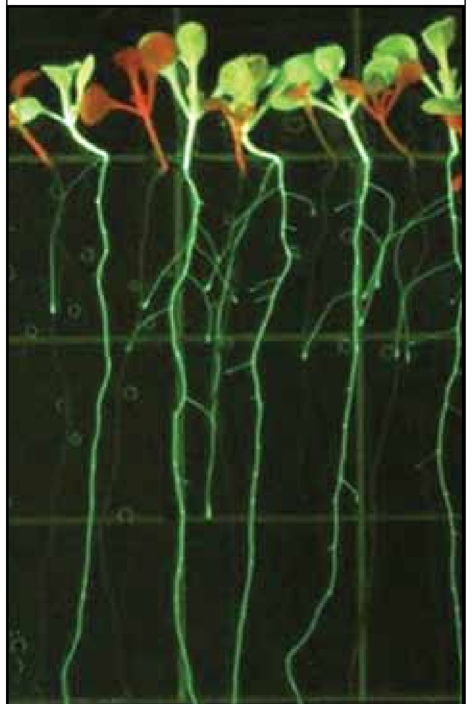
The first of the two experiments, a stem cell regeneration experiment in microgravity conducted by Ames and the University of California-San Francisco, examined cell activity using mouse embryonic stem cells in the CCM. Results from this study will identify potential mechanisms inside cells that function in tissue development and wound healing.

The second experiment, devised by Arizona State University's Biodesign Institute, investigated immunity and cell infection in microgravity, examining the impact of space flight on bacterial infections by conducting the first controlled, in-flight bacterial infection of human cells with *Salmonella typhimurium*—a microbe that can cause severe illness and is typically contracted through contaminated food. This study focused on the processes of bacterial infection and how cells respond to infection during spaceflight. This experiment has the potential to help scientists identify new anti-microbial targets and will further the understanding of bacterial infection processes and how cells respond to these infections. The knowledge gained will be critical in developing new anti-infective agents for space biomedical applications and combat casualty care for soldiers.

"DoD has been actively collaborating with NASA in support of cell and regenerative medicine initiatives including adult stem cell therapeutics," says Tom Cannon, vice president and co-founder of Tissue Genesis Inc. "On STS-135 we were one of two DoD experiments studying the healing potential of regenerative cells. This research helps us better understand adult stem cell biology and how to optimize our regenerative cell population. This same cell population recovered from adipose tissue (fat) is currently in FDA clinical trials as we begin to translate its tremendous therapeutic potential into the clinic."

Plants and Partnerships

Willows, spruce, mustard plants—what sounds like a partial summary of a botany survey course is actually part of a series of studies enabled by a partnership between Kennedy Space Center and the Canadian Space Agency. The partnership led to the development of a new, remotely operated Advanced Biological Research System (ABRS), which flew on the ISS in 2009. Over a 181-day period, the ABRS supported plant biology studies involving the three kinds of plants that may provide insight into how



Arabidopsis plants as viewed by the Green Fluorescent Protein Imaging System in an ISS investigation of gene expression related to plant stress responses.

the conditions of microgravity affect genetic processes and the fundamental mechanisms of wood formation. This knowledge could enable scientists to produce more commercially valuable varieties of trees.

Developed by Kennedy with engineering support provided by the Bionetics Corporation of Yorktown, Virginia, the ABRS was designed to support the growth of plants and other biological payloads in space with new remotely controlled features. It accommodates a Green Fluorescent Protein Imaging System that monitors the genetic activity associated with plant stress responses. This technology provides a new analysis capability for ISS biological experimentation that greatly reduces the amount of biological specimens that need to be returned to Earth for study—currently a key constraint for ISS science. The ABRS is now installed on the ISS for future use.

Before beginning these studies, NASA and CSA developed an "International Space Life Sciences Agreement" that established each partner's role and responsibilities; both agencies have noted that without development of this agreement, it is unlikely that the experiments could have been successfully completed or the new ABRS technology successfully developed.

Combating Muscle and Bone Loss

Astronauts who spend months in microgravity on the ISS exercise vigorously in an attempt to minimize the loss of muscle and bone mass. Even with exercise, significant loss occurs, presenting health challenges to future, longer-duration human exploration beyond low Earth orbit.

To address this challenge, a partnership was formed by Amgen Inc. of Thousand Oaks, California, BioServe Space Technologies at the University of Colorado, and Ames Research Center. Amgen proposed the evaluation of a novel drug that inhibits the action of myostatin, a

STS-118 Mission Specialist Tracy Caldwell and Pilot Charles Hobaugh check on mice that were part of a study examining a new drug's ability to preserve muscle mass and strength in microgravity by inhibiting the body's production of the protein myostatin. Partnering with NASA on this study were BioServe Space Technologies and Amgen Inc.

protein shown to be a critical regulator of muscle size. Animals, including humans, with defective or reduced myostatin have larger muscles. An increase in myostatin, such as seen during spaceflight, could stimulate muscle loss in astronauts; countering this increase could help preserve muscle mass and strength.

The partners first tested this hypothesis on the ground, treating mice with the myostatin inhibitor to prevent muscle loss that occurs with disuse. Results of the ground studies were positive, and mice were then flown to the ISS in August 2007 to perform the experiment in space. In the experiment, the drug helped mitigate mouse muscle mass and strength losses, particularly in the kinds of muscle typically most affected in microgravity, and the drug-treated flight mice increased their mass over placebo-treated animals on the ground.

With minimal apparent side effects, the Amgen drug appears to be a good candidate to serve as a countermeasure to muscle loss in astronauts. This therapy, if proven effective in spaceflight, could allow astronauts to "hit the ground running" when they land on another planet or when they return to Earth.

The drug candidate could also help Earth-bound patients recover from injury, surgery, and extended bed rest; counter the effects of muscle wasting due to muscle diseases like muscular dystrophy and muscle loss from aging—yet another example of a unique outcome from space research that may soon help improve life on Earth. ■

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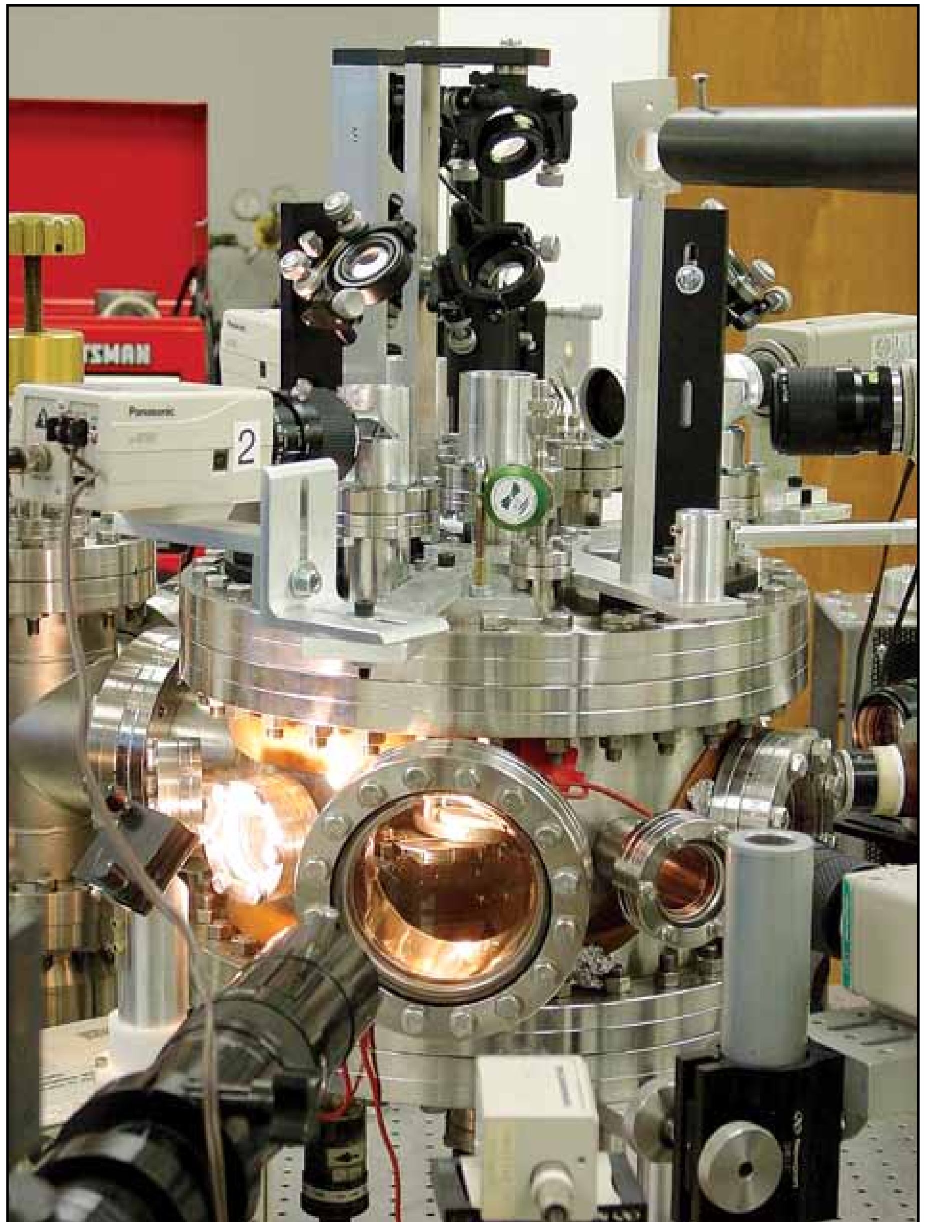
STRANGE BEHAVIOR

The Odd Effects of Microgravity Help NASA and Its Partners Advance Physical Science and Innovative Technologies



In parallel with microgravity experiments on metallic glass-forming liquids conducted onboard the Space Shuttle, ground-based research was taking place using the Caltech High Vacuum Electrostatic Levitator facility, developed at NASA's Jet Propulsion Laboratory. The main chamber of the levitator is shown here.

By Francis Chiaramonte, Ph.D.
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Boiling liquids—with bubbles that do not rise. Circular flames burning around droplets of fuel. Crystals unlike any seen on Earth.

These may seem like descriptions from a fantasy novel, but these remarkable physical phenomena can actually occur just beyond the Earth's atmosphere, in the microgravity of low Earth orbit. Whereas on Earth the force of gravity is a significant influence on how fluids and materials behave, in space the lack of gravity plays an equally significant role, producing very different effects.

From the early days of human spaceflight to the International Space Station (ISS), NASA has been conducting experiments in space to understand the effect of weightlessness on biological and physical systems. NASA's Physical Science Research Program, along with its predecessors, has conducted significant fundamental and applied research, both which have led to improved space systems and produced new products offering benefits on Earth.

NASA's experiments in various disciplines of physical science reveal how physical systems respond to the near absence of gravity and the typical phenomena affected by it. They also reveal how other forces that on Earth are small compared to gravity can dominate system behavior in space.

In the current ISS era, the United States now has an orbiting National Laboratory that provides a facility for conducting long-duration experiments in microgravity. This allows continuous and interactive research similar to Earth-based laboratories, enabling scientists to pursue innovations and discoveries not currently achievable by other means. NASA research efforts like the Physical Science Research Program also benefit from collaborations with several of the ISS international partners—Europe, Russia, Japan, and Canada—and foreign governments with space programs, such as France, Germany and Italy. The scale of this research enterprise promises new possibilities in the physical sciences, some of which are already being realized both in the form of innovations for space exploration and in new ways to improve the quality of life on Earth.

Protecting Respiratory Health

One example relates to the clean air needed for good health, whether on the ground or in a spacecraft. Everyday industrial activity on Earth creates and disperses submicron particles—pieces of solids smaller than a micron, or one-millionth of a meter—that are harmful to human respiratory health. However, to date, the existing technologies available for measuring these dangerous pollutants are typically too large, draw too much power, and are too fragile and complicated to operate—particularly in the harsh environment of space. This is the case for many problems of importance to NASA, such as assessing and maintaining air quality in spacecraft, aircraft, and remote space colonies, or detecting and characterizing particles in planetary environments.

To this end, Glenn Research Center and university colleagues have been involved in an effort to develop robust and compact particle sensor technologies. Such sensors represent an important and enabling step for NASA, and they have many applications on Earth as well, such as monitoring the exposure of workers to unhealthy particulates during welding and machining; real-time assessment and protection of emergency responders and the general public during demolitions, fires, and catastrophes; and enabling scientists to understand the health effects of long-term exposure to particulate pollutants.

The range of particles of most interest to human health is called the respirable fraction—particles smaller than 10 microns in diameter. One of the most challenging measurement aspects has been to include the so-called "ultrafine fraction," which refers to particles that are smaller than 100 nanometers—a nanometer being one-billionth of a meter. Most recently, ultrafines have drawn significant attention in the respiratory health community, as their extremely small size causes them to interact with the body in unique and often harmful ways.

One technique for characterizing these ultrafine particles is called Electrical Mobility Classification. A novel, miniature device for this purpose was developed by NASA's Fire Safety Project in collaboration with Washington University in St. Louis. The technology is significantly more compact than existing instruments and is capable of sampling, analyzing, and logging the size distributions of breathable particles. This Microscale Particulate Classifier was developed as a spinoff of two other projects: the spacecraft smoke detector, a prototype of which was flown on the ISS with the Smoke and Aerosol Measurement Experiment, and the lunar dust sensor.

The ability to perform particle measurements in the field will serve to advance researchers' understanding of respiratory health factors and help to monitor and maintain a healthy environment. The NASA mini-classifier provides a useful new tool, allowing the rapid and widespread measurement of particulates in a wide variety of previously inaccessible conditions.

This technology was recently licensed to TSI Inc., the largest worldwide manufacturer of particulate measurement instrumentation, meaning the unique capabilities of this NASA technology will soon be available commercially to help assess air quality both in the industrial workplace and for the public at large.

From Sporting Goods to Cell Phones

Consumer products also feature the results of physical science research enabled by the conditions of low Earth orbit. Liquid metallic alloys, which vitrify, or form glass, as they cool from the molten state, were first reported in 1960.

By 1980, manufacturers could produce thin, continuous ribbons of metallic glasses using iron-based, nickel-based, and titanium-based alloys. The iron-based "melt spun" ribbons were found to have exceptional magnetic properties and were adopted to replace traditional alloys to improve the energy efficiency of transformers and inductors and to power electronic devices. These iron-based metallic glasses are today the standard material for the energy-efficient magnetic cores in the U.S. power distribution grid.

A series of advances in bulk metallic glass took place beginning in the 1980s, leading to the discovery of novel families of zirconium/titanium-based alloys, the so-called Vitreloy alloys, that could be cast into three-dimensional metallic glass components.

As part of the effort to understand glass formation and crystallization in glass-forming metallic liquids, microgravity experiments were conducted aboard the space shuttle during the 1990s. These experiments employed the TEMPUS facility, an electromagnetic melting and processing system developed by the German Space Agency (DLR) and utilized by a joint DLR/NASA scientific team. In parallel with flight experiments, ground-based experiments were conducted using a High Vacuum Electrostatic Levitator (HVESL) facility developed at the Jet Propulsion Laboratory. Data gathered from both ground-based and low-Earth orbit experiments proved critical for understanding the properties and crystallization of the glass-forming liquids. An additional study conducted on the ISS by Marshall Space Flight Center further investigated the properties of these unusual substances.

CREDIT: LIQUIDMETAL TECHNOLOGIES

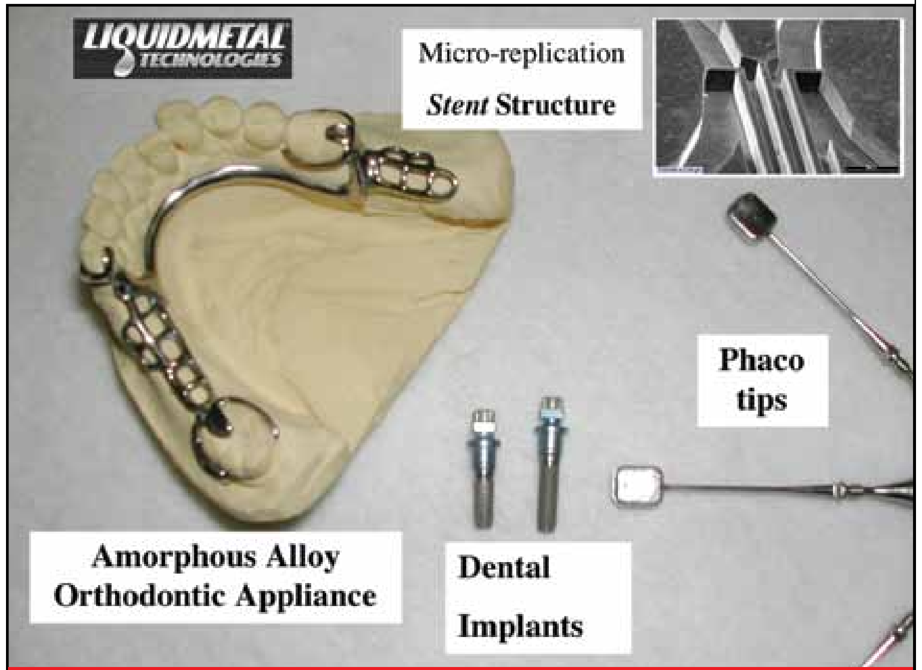
DATA PRODUCED BY NASA EXPERIMENTS ON METALLIC GLASS FORMING LIQUIDS WAS INSTRUMENTAL IN DEVELOPING METALLIC GLASS HARDWARE PRODUCED BY LIQUIDMETAL TECHNOLOGIES AND ADOPTED IN PRODUCTS MANUFACTURED BY MOTOROLA, SAMSUNG AND LG ELECTRONICS.

The TEMPUS and HVESL results were key to later development of the Vitreloy glasses for commercial uses. In 1997, Liquidmetal Technologies of Rancho Santa Margarita, California, introduced these materials, and the high strength and mechanical properties of metallic glasses, combined with the development of die-casting technology, led to their use as structural materials for frames, casings, hinges, and biomedical hardware.

"On-orbit research using both the space shuttle and ISS allowed us to gather critical data on these materials as well as providing us a platform for "outside-the-box" thinking about applications for metallic glasses," says Douglas C. Hofmann, Ph.D., a former research and development scientist at Liquidmetal who now is at the Jet Propulsion Laboratory developing a metallurgy lab to continue work in metallic glasses. "We are now seeing the fruit of those efforts with the widespread commercialization of metallic glass products, from golf clubs to cell phones."

Liquidmetal's NASA-derived alloys have since featured in sporting goods and have been adopted by Motorola, Samsung, LG, and Sandisk for use as casings and functional components in cell phones, thumb drives, and other portable consumer electronic devices.

CREDIT: LIQUIDMETAL TECHNOLOGIES



SHOWN HERE ARE ADDITIONAL EXAMPLES OF METALLIC GLASS HARDWARE PRODUCED BY LIQUIDMETAL TECHNOLOGIES AND BASED ON DATA FROM NASA EXPERIMENTS.

The recent acquisition of Liquidmetal's manufacturing know-how and intellectual property by Cupertino, California-based Apple Corporation suggests a continued bright future for metallic glass technology in the consumer electronics field.

Lessons from an Astronaut's Coffee Cup

One well-known physical phenomenon that on Earth is dominated by the force of gravity enjoys freedom—and significantly more influence—in space. In the near-weightless environment of low Earth orbit, capillary forces, the molecular attractions between a liquid and a solid surface, present significant challenges to spacecraft designers.

On Earth, capillary forces are weak compared to gravity, but are behind many familiar capabilities, like that of a paper towel to absorb water, or a lantern wick to draw oil up its length. In microgravity, with no "up" or "down," it becomes difficult to control liquids with the same methods as employed on the ground, and these poorly understood forces can dominate fluid behavior to the extent of altering a spacecraft's center of mass in the case of large liquid fuel tanks, or by moving fluids such as water, coolant, condensate, or urine to places they should not be. This situation poses particular challenges to spacecraft designers because numerous spacecraft systems demand liquids, whether they are fuel for the vehicle or water for the crew.

During the design of the ISS, systems were constructed in ways—such as through rotating machinery that mimics gravity—to prevent capillary forces from interfering with the station's operations. Such approaches have worked, as evidenced by the highly functional space station. However, rotating equipment requires service that is not easy to provide in orbit, and other solutions are also imperfect; a single liquid phase system, for example can develop gas bubbles that can stop or interrupt fluid flow, which can cause a system, such as a water recycler or propellant tank, to stop working.

Nonetheless, NASA has continued to pursue research relating to the management of liquids in low-gravity environments by exploiting the capillary forces rather than simply overpowering or avoiding them. Experiments performed in microscale systems, drop towers, low-g aircraft, the space shuttle, the Mir Space Station, and now the ISS have continued to increase researchers' knowledge and ability to employ capillary forces to enhance system performance or even drive new systems. Insights relating to manipulating capillary forces now serve as a foundation for the next generation of fluid systems design for spacecraft. These advanced systems offer enhanced performance and significantly increased reliability since they draw from passive forces in specially shaped containers with no moving parts.

Research results from experiments such as the Capillary Flow Experiments (CFE) on the ISS provide a case in point. One example was presented in the NASA TV footage (now a popular Youtube video) of the "astronaut coffee cup," where a passive capillary flow generated by a sharp interior edge in the cup in effect replaces the pumping action of gravity, allowing the astronaut to drink "normally." Such forces result from the container's geometry and have been applied successfully in numerous advanced system designs. One example is a multifunctional, condensing heat exchanger that preferentially condenses, collects, wicks, and recovers water from moist air passively, without moving parts and without gravity.

IMAGE CAPTURE FROM A VIDEO SHOWS ASTRONAUT DON PETTIT DEMONSTRATING PASSIVE CAPILLARY FLOW BY DRINKING FROM A COFFEE CUP IN MICROGRAVITY. THE CAPILLARY FLOW EXPERIMENTS CONDUCTED ON ISS HAVE LED TO APPLICATIONS INCLUDING METHODS TO DESIGN SURFACE MICRO-STRUCTURES TO ENHANCE EVAPORATIVE HEAT TRANSFER, AND METHODS TO DESIGN LOW-COST AIDS TESTS.

Evan Thomas, Ph.D., assistant professor at Portland State University, worked on life support systems including microgravity fluid management and water treatment systems while an engineer at Johnson Space Center. He talks about the importance of these capillary fluid management experiments in teaching engineers how to design more sustainable, robust technologies that will benefit space exploration as we send humans further away from the Earth.

"When you're more than a few days, weeks or months from resupply, your life support technologies need to function with greater reliability," he says. "One important factor is how to manage fluids in the absence of moving parts, while accommodating changes like biological growth or differences in fluids over time. The capillary fluids experiments are helping us design technologies that can exploit fluid behavior, and control without complex moving hardware."

Earth-bound applications that take advantage of capillary forces have now arisen, including everything from methods for enhancing evaporative heat transfer in heat spreaders and heat pipes to methods for improving quality in inkjet printing.

"These capillary fluid experiments may soon be applied to lab-on-chip instruments that exploit fluid behavior, like blood or water, to study various properties like infection or contamination. Or they may be applied to microbiological studies, that examine how fluids interact with biological growth," he continues.

These benefits and others continue to increase as NASA research results become more widespread—demonstrating the far-reaching influence that the Agency's space-based efforts in the physical sciences have here at home. ■

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An Emphasis on Partnership

The ISS as an International Research Collaboration

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It's called the International Space Station (ISS) for a reason: Several years before the first module of the ISS was launched in 1998, a collaboration developed among the Canadian Space Agency (CSA), European Space Agency (ESA), Japanese Aerospace Exploration Agency (JAXA), Federal Space Agency of Russia (Roscosmos), and NASA. Since then, this partnership has weathered financial, technical, and political challenges, proving that nations can work together to assemble the largest space vehicle in history. And while the ISS partners can be proud of having completed one of the most ambitious engineering projects ever conceived, the challenge of successfully using the platform remains.

During the ISS assembly phase, the ISS partners demonstrated the potential benefits of space-based research and development, including the advancement of scientific knowledge from space-based experiments, the development and testing of new technologies, and the derivation beneficial outcomes on Earth from new understandings acquired in space. In addition to the obvious uniqueness of its location in low Earth orbit, the configurability of the station, the availability of the ISS crew to tend experiments, and the opportunity for researchers to complete follow-on investigations within a period of months all contribute to make the ISS a truly one-of-a-kind laboratory.

Crewmembers from ISS Expedition 20 represent five nations and the five partners in building the ISS: (Clockwise from 12:00) Frank De Winne, Belgium, European Space Agency; Gennady Padalka, Russia, Roscosmos; Robert Thirsk, Canadian Space Agency; Koichi Wakata, Japan Exploration Aerospace Agency (JAXA); Michael Barratt, U.S., NASA; Roman Romanenko, Russia, Roscosmos.

"The International Space Station provides the most comprehensive platform available for doing research in Earth orbit, with resources to do well-controlled experiments exposing biological organisms to low gravity," says Catharine A. Conley, Ph.D., who is principal investigator of a study to learn more about the effects of the spaceflight environment on living systems, discussed later in this article.

The international strategy for making the most of the capabilities of the ISS is based on research ranging from physical sciences, biology, medicine, and psychology to Earth observation, human exploration preparation, and technology demonstration. During the current utilization phase, the ISS partners are working to track objectives, accomplishments, and the applications of the new knowledge gained. Areas of current research on the ISS with strong international cooperation include everything from cardiovascular studies to cell and plant biology, radiation, physics of matter, and advanced alloys. Scientific knowledge and new technologies derived from research on the ISS will be realized through improving quality of life on Earth and future spaceflight endeavours.

Working Together to Realize Potential

NASA and its international partners have worked together to conduct a total of 1,149 experiments from 1998 through September 2010. One of the first experiments conducted on the ISS studied complex plasma crystals, a new kind of matter composed of ionized gas, neutral gas, and micron-sized particles. The microgravity environment of the ISS provided the conditions necessary to develop larger three-dimensional plasma crystals in a weaker electric field when compared with crystals produced on Earth, revealing the unique structural details of the crystals and helping researchers acquire a better understanding of plasma in space. This successful Roscosmos-sponsored experiment has led to additional experiments sponsored by ESA.

Also sponsored by ESA is the Geoflow experiment, which uses a model of the Earth's crust and a liquid core comprised of silicone oil to evaluate fluid behavior under different conditions, potentially providing information on flow in the Earth's atmosphere and oceans and the movement of Earth's mantle on a global scale, as well as other astrophysical and geophysical problems. Results from Geoflow also will be useful for making improvements in a variety of engineering applications, such as spherical gyroscopes and bearings, centrifugal pumps, and high-performance heat exchangers.

Frequently, scientists from different countries collaborate on a single experiment. One example is an international experiment conducted by investigators from Canada, France, Japan, and the United States, who worked together to study microscopic *C. elegans* worms while onboard the ISS. Each team studied a different aspect of the effects, which included radiobiology, muscle protein changes, aging, reaction to radiation, and DNA damage and repair.

"Results from exposure experiments by my collaborators have illuminated a range of biological responses in the nematode worm *C. elegans* over multiple generations, that were not previously known, says Dr. Conley, who in addition to her role as principal investigator is also planetary protection officer in NASA's Science Mission Directorate. "These results expand our understanding of basic biological processes, and could contribute both to improvements in biomedical treatment for muscle diseases on Earth and support for astronaut health on long-duration deep space missions."

Healthy Returns

Recent NASA ISS studies have delivered new discoveries and techniques for medical treatment. An Agency experiment examining virulence and drug resistance in microorganisms while in space has shown an increase in microbial virulence in some species when activated in microgravity, meaning they multiply at a faster rate, turning some previously harmless microbes into potential pathogens. Through this body of research, the scientists have identified the controlling gene responsible for the increased virulence of *Salmonella typhimurium*. Studies like this one will help researchers identify germs that can cause illness in both astronauts and people on Earth and help to develop vaccines and other treatment strategies to counter those diseases.

Along those lines, the Surface, Water and Air Biocharacterization experiment—or SWAB—provided a method of on-orbit microbial analysis that could detect far more types of harmful microorganisms than standard ISS culture testing, including *Legionella* (the bacterium that causes Legionnaires' disease) and *Cryptosporidium* (a parasite common in contaminated water). SWAB will provide insight into the risk posed to astronauts by certain organisms during spaceflight.

A hand-held, lab-on-a-chip device developed by NASA also has the potential to provide astronauts with a rapid indication of biological cleanliness to help crew monitor microorganisms in the ISS cabin environment. The Lab-on-a-Chip Application Development-Portable Test System (LOCAD-PTS) rapidly detects biological and chemical substances on surfaces aboard the station. It allows astronauts to swab surfaces within the cabin, mix the material in liquid form to the LOCAD-PTS, and obtain results within 15 minutes on a display screen.

Credit: C. Egbers, BTU Cottbus

This interferogram is from the European Space Agency-sponsored Geoflow experiment, which models the Earth's crust and liquid core. Here, silicone oil is used to understand fluid under different condutions. Applications include atmospheric and oceanic flow, and global movement of the Earth's mantle. Results from Geoflow will be useful in improving engineering applications such as spherical gyroscopes and bearings, centrifugal pumps and high-performance heat exchangers.

"The LOCAD-PTS experiment onboard ISS addressed the need to obtain timely biological assay information to support environmental and crew health decisions. We showed that microbial contamination measurements could be made on surfaces in minutes versus several days now needed for conventional culture. Also, the technology requires very minimal upmass, or equipment delivered into orbit, and no downmass, or equipment to be delivered back to Earth," says Norman R. Wainwright, Ph.D., LOCAD-PTS principal investigator and director of research and development at Charles River Laboratories, Inc., in Charleston, S.C. "Future enhancements to the technology will allow expansion to measure many specific parameters simultaneously and support human and robotic exploration missions."

Another NASA initiative, conducted in partnership with Henry Ford Hospital in Detroit and Wyle Laboratories Inc. in Houston, has resulted in techniques and training methods for long-distance, diagnostic ultrasound. Since the ISS has no X-ray or MRI machines, NASA and its partners developed new ways to use the station's ultrasound machine to diagnose illnesses and injuries. The innovations have been incorporated by the American College of Surgeons Committee on Education into a computer-based program to teach ultrasound to surgeons, and Mediphan Inc. of Canada developed technology for transmitting and storing ultrasound imagery over the Internet to enable near real-time diagnosis for patients miles away from the examining physician. The remote guidance techniques have been used to provide care for Olympic and professional athletes, as well as for connecting doctors to patients in remote areas, such as Inuit communities in the Arctic Circle.

Other internationally driven, health-related ISS research includes a CSA study into the root causes of the decline in perceptual motor coordination (such as fine hand-eye coordination) observed during the period of adaptation to spaceflight. The results showed cognitive overload and stress caused the issues, rather than changes brought about by microgravity—findings that will help with training for and operations in space. In addition, a JAXA-Roscosmos collaboration examined crystals of a protein that is a possible candidate treatment for Duchenne's muscular dystrophy, which results in muscle wasting, difficulty walking and breathing, and eventual death.

Russian cosmonaut Alexander Skvortsov, Expedition 24 commander, performs chamber leak checks on the Plasma Crystal-3 Plus experiment in the Poisk Mini-Research Module 2 of the ISS.

Present and Future Possibilities

The international research endeavors underway on the ISS are not only revealing more about physical matter and human health, but also about the greater universe. A JAXA-sponsored experiment is using highly sensitive X-ray slit cameras to monitor more than 1,000 sources of X-rays in space and providing that information to astronomers and observatories worldwide. And a newly launched particle physics detector—a joint effort between NASA and space agencies in Europe and Taiwan—uses the environment of space to search for antimatter and dark matter and measure cosmic rays. The device is expected to advance knowledge of the universe and lead to increased understanding of its origin.

The ISS represents not only broad perspectives for a new future in scientific discoveries, but a community of international collaborators that has overcome financial, technical and political challenges to assemble one of the greatest engineering accomplishments. The opportunities this feat provides are now shared with the world. The ISS partner agencies have a joint database containing summaries of the research conducted on the space station, tracking experiments from the start until the final results are published. Future generations of scientists and engineers are also taking part through international educational activities such as those conducted by the CSA, the International Space University, and CSA ISS crew member Robert Thirsk—which alone involved 1.85 million students in hands-on learning related to ISS science.

The extension of ISS operations through 2020 promises to allow the international partnerships the station has fostered to further develop and mature. As these collaborations continue to reach for extraordinary achievements in science and technology, the results will be beneficial for mankind and for the future of space exploration. ■

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PEN CAPS AND NANOPARTICLES

Inspiring, Engaging, and Educating the Next Generation through ISS Research

By Mark T. Severance, NASA Johnson Space Center

Butterflies, rubber bands, empty shampoo bottles, fruit drinks, hot sauce: These are probably not items that would turn up in the average space researcher's inventory. But there is very little that is typical about the educational opportunities NASA offers to students around the Nation through the unique laboratory known as the International Space Station (ISS).

Education has always been an important component of the NASA mission. The genesis of today's NASA Office of Education is contained within the founding legislation of the Agency, the Space Act of 1958. For this reason, conducting educational activities on NASA human spaceflight missions or from onboard the ISS is not a new concept. Many such activities and payload operations have been sponsored by NASA and the ISS program's international partner space agencies, involving more than 31 million students worldwide in just the first six years of ISS permanent occupation.

In 2007, as part of the 21st Century Competitiveness Act Conference Report, the Agency received additional direction to use the ISS National Laboratory to support science, technology, engineering, and math (STEM) education.

What is new and different is a mandate by the U.S. Congress to incorporate education as part of the ISS National Laboratory effort. Specifically, NASA has been given congressional direction to pursue activities in collaboration with businesses, academic institutions, nonprofit organizations, other U.S. government agencies, and ISS program partner space agencies to use the ISS National Laboratory to support science, technology, engineering, and math (STEM) education—and in doing so provide a foundation for the Nation's future innovators, scientists, and industry leaders.

In conjunction with the ISS National Lab Education Project, NASA will continue its traditionally successful educational efforts, including projects managed by the Teaching from Space Office at NASA Johnson Space Center. Payloads and activities such as Earth Knowledge Acquired by Middle School Students (EarthKAM), Amateur Radio on ISS (ARISS), and ISS Education Downlinks have a lengthy history of successful operations and have involved hundreds of thousands of students throughout the world.

Under the project, NASA continues to expand opportunities in STEM education for students from kindergarten through post-graduate school. Partnering opportunities enabled by the ISS National Laboratory will provide new ideas and resources for ISS-related educational activities and payloads. At its core, the project strives to allow students, educators and the general public worldwide to participate in the ISS mission. Consistent with the goals of the NASA Office of Education, the project will contribute to developing the next generation of innovators in disciplines needed to meet NASA's strategic goals; attracting and retaining students in STEM disciplines through a progression of education and research opportunities for students, formal and informal educators and faculty; and building strategic partnerships that promote STEM literacy through formal and informal educational opportunities. Activities to further include international students, as well as students from traditionally underrepresented and underserved institutions, will also be emphasized.

In doing so, the ISS National Lab Education Project will serve as an educational resource for educators, students and life-long learners for the duration of the ISS program. Here are a few examples of the educational opportunities enabled by NASA and the ISS so far.

NASA Astronaut Scott Kelly with three Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) floating in the ISS in November 2010. SPHERES was developed by MIT with support from DARPA, DoD and NASA to test control algorithms for spacecraft by performing autonomous rendezvous and docking maneuvers inside the station.

Education, Cubed

In January 2011, the successful docking of the Japanese Space Agency's HTV-2 cargo vehicle brought to the ISS experiments from the Valley Christian School of San Jose, California, and The Ohio State University (OSU). In the first ever commercial ISS high school project, Valley Christian is undertaking a botany experiment. OSU's research project is focused on isolating the effect of gravity on the growth of certain nanoparticles.

Both experiments traveled in CubeLabs, containers produced for this purpose by NanoRacks LLC of Laguna Woods, California, and its partner, Kentucky Space. Through a Space Act with NASA, NanoRacks is providing commercial opportunities in the U.S. National Lab onboard the ISS. NanoRacks provides hardware and services, with two research platforms that can house plug-and-play payloads. The nonprofit Kentucky Space enterprise focuses on research and development, educational, and small entrepreneurial and commercial space solutions involving several universities in the state of Kentucky. The Kentucky Space model gets students involved in multiple aspects of space research, from the development of the NanoRacks host flight hardware to the development and operation of experiments sponsored by the payload customer school.

"For both educational payloads," says NanoRacks managing director Jeffrey Manber, "the schools went from zero to docking in less than nine months. That's a great benchmark of what is now possible on the U.S. National Lab."

Batteries Included

They look like brightly colored toys, and are even powered by AA batteries, but the Synchronized Position Hold Engage and Reorient Experimental Satellites (SPHERES) are actually a serious tool for both education and technological development.

Under the supervision of an ISS astronaut, SPHERES satellites operate inside the modules of the ISS, using pressurized carbon dioxide for propulsion. In August 2010, as part of NASA's Summer of Innovation program and with funding provided by the Massachusetts Space Grant, middle-school students from 10 schools and educational groups were involved in a SPHERES competition in which the satellites simulated the assembly of a larger satellite. They first navigated through virtual obstacles, and reached a docking location—for example, where a new virtual part would be picked up. They then went on to the finish area, where the virtual part was assembled. The students were then required to program the satellite to perform these steps autonomously, without any human intervention once NASA Astronaut Shannon Walker began the tests.

As part of the new Zero Robotics competition, middle- and high-school students will program SPHERES for autonomous operations. After the students complete their software, they will watch as the satellites race against each other to perform engineering tasks. The races will take place in simulation at the Massachusetts Institute of Technology, and then onboard the ISS.

College students also use SPHERES to test new ways to control satellites, and NASA uses the satellites as a testbed for formation flying and multiple body control algorithms.

Buzz Lightyear ™ was the inspiration for NASA's Kids In Micro-g Challenge and host of the Buzz Lightyear ISS Mission Log special feature videos, produced by Disney/Pixar.

Butterflies in Space

In a special habitat on the ISS, Painted Lady butterfly larvae completed their lifecycles under the watchful eyes of students on Earth.

Participating were more than 180,000 students. The students conducted their own open-ended investigations of the growth, development, and behavior of the butterflies growing in microgravity conditions inside the Commercial Generic Bioprocessing Apparatus (CGBA) Science Insert onboard the ISS, while comparing these to similar butterflies under the normal gravity conditions in their own classrooms.

The Butterflies in Space experiment was developed by BioServe Space, a component of the University of Colorado, in conjunction with the Baylor College of Medicine and the National Space Biomedical Research Institute.

Another CGBA Science Insert payload launched in early 2011 to the ISS to study orb-weaving spider behavior, fruit fly behavior, and seed germination.

Space Science with Shampoo Bottles

Not all student experiments have involved the use of sophisticated payload hardware onboard the ISS. The Kids In Micro-g (KiMG) design challenge was developed with the opposite in mind.

Given a set of simple items commonly found in classrooms as well as onboard the ISS, students in fifth through eighth grades were asked to develop a microgravity experiment or demonstration that would have an observably different outcome in the classroom than when performed by astronauts in the microgravity environment of the ISS.

Nine student-developed experiments were selected. Materials ranged from rubber bands to a pen and paper, pen caps, empty shampoo bottles, fruit drinks, and hot sauce. The experiments were designed to examine phenomena associated with projectile motion, microgravity interaction of objects, fluid mixing and absorption, and astronaut adaptability to microgravity.

"Activities like Kids in Micro-g allow students to apply the basic concepts they are learning in their classroom to a real-world experiment environment," says KiMG Principal Investigator Deborah Biggs of Johnson Space Center. "And, it provides us with an opportunity to help grow critical thinkers that will hopefully become part of the science, technology, engineering and mathematics workforce of the future."

KiMG was rolled out as part of the informal education activities of the Buzz Lightyear on ISS public outreach activity. In conjunction with the activity, two special feature videos of "Buzz Lightyear's ISS Mission Logs" were included in the re-release of the films Toy Story and Toy Story 2 on DVD.

The Disney/Pixar special feature videos, written in consultation with staff from the ISS National Lab Education Project, target younger audiences with explanations of the basic concepts of spaceflight, the construction and operation of the ISS, and life and work onboard the space statio.

Results by Radio

ISS education programs occur outside the station's pressurized modules as well. Educational satellites in the larger (50-pound) microsat class are under development by The Radio Amateur Satellite Corporation (AMSAT), a not-for-profit organization based in Silver Spring, Maryland. AMSAT is the hardware provider for the ISS ham radio payload that is used for the ARISS program, which allows students to speak directly with ISS crew members with the help of amateur radio clubs and ham radio operators.

AMSAT volunteers developed ARISSat, an educational satellite with the capability to carry four to five student-developed experiments. In addition to providing space communications capabilities for use by amateur radio operators worldwide, ARISSat can provide data telemetry from its onboard student experiments via amateur radio links. ARISSat is being developed in conjunction with S.P. Korolev Rocket and Space Corporation Energia of Russia and the ISS National Lab Education Project.

ARISSat-1, the first of a planned series of ARISSat satellites, was launched to the ISS in early 2011 and manually deployed by ISS Cosmonauts during a spacewalk August 3, 2011. Aboard ARISSat-1 is an experiment from Kursk University in Russia, designed to derive atmospheric density measurements based on readings from an onboard pressure sensor. Experiment data will be downlinked via amateur radio until the satellite's orbit decays and the satellite is destroyed during re-entry.

AMSAT President Barry Baines noted, "ARISSat-1 marks a new type of satellite which has captured the attention of the national space agencies around the world for the unique educational opportunity we have been able to design, launch, and now operate. By designing an educational mission aligned with NASA's Science, Technology, Engineering, and Mathematics amateur radio operators around the world can now enjoy a new satellite in orbit."

Investigating a HUNCH

Some ISS educational activities take place far from the ISS itself. In the High Schools United With NASA to Create Hardware (HUNCH) program, middle- and high-school students build flight and training hardware for use in the ISS program. HUNCH currently involves more than 20 schools in eight states.

Mentored by NASA professionals, students participate in all aspects of the design and fabrication of ISS hardware, which has ranged from cargo transfer bags to avionics training equipment used in ISS simulators at NASA's Marshall Space Flight Center and Johnson Space Center. NASA funds the HUNCH program and realizes a significant cost savings due to the production of professional grade hardware required for ISS operations at essentially a materials-only cost.

The program has been expanded to provide engineering project management experience for college level students. Students at Lone Star College in CyFair, Texas, manage the production of ISS training hardware fabricated at several middle and high schools in their local area. NASA plans to expand the engineering project management aspect of HUNCH to other colleges and universities in the coming year.

Mark T. Severance is ISS National Laboratory Education Projects Manager in the Office of Education at NASA Johnson Space Center

For more information, contact Susan White at susan.m.white@nasa.gov.

Please mention that you read about it in Technology Innovation.

NASA Field Centers Contribute to the ISS

Each of NASA's 10 Field Centers, spread throughout the United States, plays a role in making the International Space Station a success.

Ames Research Center

Moffett Field, California
With a long history of managing manned and unmanned spaceflight payloads, most of which have been in the life sciences, Ames also works in areas relative to the ISS such as nanotechnology, biotechnology, life support, astrobiology, small sample return, and commercial space.

Dryden Flight Research Center

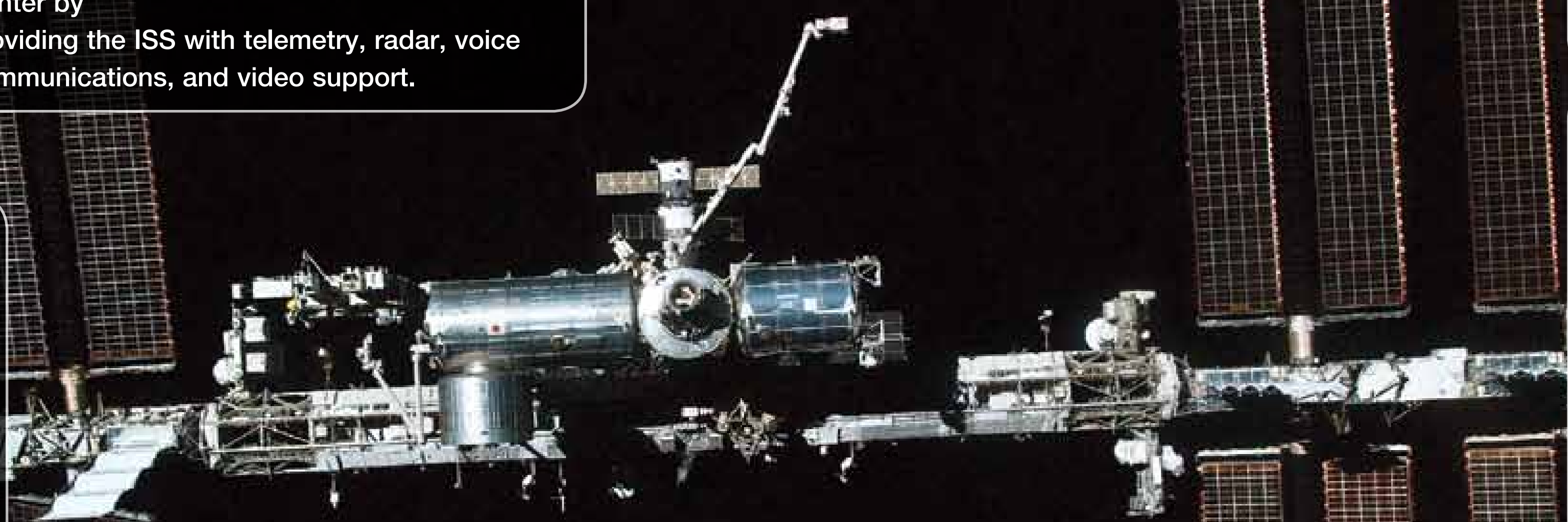
Edwards, California
Located on the Edwards Air Force Base complex, Dryden's Western Aeronautical Test Range supports Johnson Space Center by providing the ISS with telemetry, radar, voice communications, and video support.

Langley Research Center

Hampton, Virginia
Langley has been studying the effects of long-term exposure to the space environment on systems and operations for years, beginning with the Long Duration Exposure Facility from 1984-1990, and most recently with the Materials International Space Station Experiments.

Jet Propulsion Laboratory

Pasadena, California
As the manager of the Deep Space Network, an international network of antennas that supports interplanetary spacecraft missions, including the ISS, and radio and radar astronomy observations for the exploration of the solar system and the universe, JPL also supplied and tested sensors that monitor astronaut health onboard the ISS.



Kennedy Space Center

Cape Canaveral, Florida
From manufacture and assembly through verification, launch, and landing, Kennedy manages the overall ground processing for all U.S.-launched ISS elements and also supports on-orbit operations during assembly and operation of the ISS.

Glenn Research Center

Cleveland, Ohio
In addition to having developed and operated numerous experiments on the ISS, Glenn designed, developed, and operates the ISS electrical power system. Other contributions include atomic oxygen protective coatings that prevent structural failure of the station's solar array blankets and software that characterizes the microgravity environment for experiments.

Goddard Space Flight Center

Greenbelt, Maryland
As the manager of the Tracking and Data Relay Satellite System project, which provides NASA's data relay services to orbiting observatories, including the ISS, Goddard also is the main provider of NASA's unpressurized attached ISS payload platforms that provide mechanical mounting surfaces, electrical power, and services for onboard experiments.

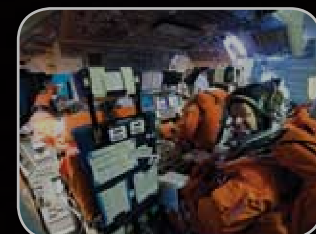
Marshall Space Flight Center

Huntsville, Alabama
Staffed 24–7, Marshall's Payload Operations Center controls the operation of U.S. experiments onboard the ISS and coordinates experiments of the partner nations onboard the ISS. The Center also oversaw development of most of the U.S. modules and the ISS Environmental Control and Life Support System.

Stennis Space Center

Mississippi
Stennis tested the main engines for all Space Shuttle flights, including those bound for the ISS. The high-performance, liquid-fueled engines had to pass a series of test firings at the Center prior to being installed in the back of the orbiter. The Center will now use its test stands, including a new 300-foot-tall test stand, for rocket propulsion testing for future space flight vehicles.

Johnson Space Center



Houston, Texas
As the lead NASA field center for the ISS and the focal point of the collaborative effort among the 16 international partner nations, Johnson is also home to the ISS astronaut office, astronaut training, mission control for ISS vehicle and mission operations, and the NASA Human Research Program.

Living & Working In Space

By Kathryn M. Duda,
National Technology Transfer Center

Astronaut Scott Parazynski floats between two Extravehicular Mobility Unit space suits in the Quest Airlock of the ISS while Space Shuttle Discovery is docked with the station during STS-120 in November 2007.

When workers were assembling the 103-story Empire State Building in 1930, they no doubt considered their work site "high-altitude." Ditto for the more recent crew that put up Dubai's Burj Khalifa, the world's tallest building at 160 stories.

But when Scott Parazynski describes himself as "an extremely high-altitude construction worker," he beats the others hands down.

An M.D. and former NASA astronaut, Parazynski participated in five space shuttle missions between 1994 and 2007 and conducted seven space walks, logging more than 47 hours outside the shuttle making repairs, installing and deploying equipment, operating the shuttle's robotic arm, evaluating tools and conducting other tasks, all while floating more than 200 miles above the Earth. At his job site in the quiet darkness of space, looking back toward Earth was not frightening as it might have been for the aforementioned terrestrial construction workers – it was awe-inspiring.

"It takes your breath away," he says of the experience. "You feel like the luckiest person alive to see that view."

But he was not in space to sightsee; there was work to be done, and he had trained long and hard to get the chance to do it. Like many aspects of life in space, however, doing one's job is much different, and often much more challenging, than it is on Earth.

It's A Gravity Thing

In space, the simplest of actions take careful thought to avoid problems, and even catastrophes. In most instances, the lack of gravity is responsible for making things challenging. Take eating for example.

"It should be basic," he says. "You heat the food, get a fork and eat." But in space, there are many more steps involved. Opening a package of food must be done with the greatest of care, lest a green bean drift away and poke someone in the eye or get caught in a piece of equipment. Since most of the food packaged for consumption in space is dehydrated, the food then must be mixed with water and left to sit and rehydrate.

"The whole concept of grabbing a quick bite – it's not going to happen in space," Parazynski says.

"You have to be mindful of the environment that you're in. You can't set anything down – a fork, a tool, a pen. You have to use Velcro, a tether or duct tape to secure it, or it will float off." The cabin air cleaner serves as the local lost-and-found – the place where errant items end up after getting caught in the air currents.

Lack of gravity also makes it difficult for astronauts to get the exercise that they need, not only to stay fit, but to overcome the bone loss that is common in space.

"We know from early shuttle missions that there is a critical need for exercise," he says. "After two to four days in space, astronauts lose significant bone density, and it happens very quickly." To overcome the challenges presented by the space environment, special equipment must be included onboard to enable astronauts to get some resistance training. Shuttle astronauts exercise for 45 minutes each day, and the ISS crew spends about two hours a day working out.

At other times the lack of gravity can be an advantage in the confines of the space shuttle, allowing crewmates to share the space without feeling crowded.

"Using the three dimensions, people can be evenly distributed," Parazynski recalls. "There are ways to make it work – some float near the floor, some near the ceiling. It's interesting to see people zip along. You make use of the confined environment, and it seems larger on orbit due to your freedom."

Space Walking - Space Working

That same sense of freedom was especially apparent during extravehicular activity (EVA), which he undertook on three of his five missions.

"There's a feeling of ultimate freedom being out there," he says of the spacewalks. "It's a distracting environment. There you are, floating, looking at the Earth – it's easy to get wrapped up in that. But your work is tightly timelined, and you have to stay focused."

Staying focused on the task at hand also helps to keep any fear from entering an astronaut's mind, and after making it through his first EVA experience, Parazynski says he was able to enjoy subsequent spacewalks even more.

"It gets better with each flight. With more experience you can observe more of the beauty of the environment, and enjoy sharing it with new crew members."

Two of his seven spacewalks were especially memorable. In the first one, during STS-86 in 1997, he and Russian cosmonaut Vladimir Titov performed a five-hour spacewalk during which they retrieved four experiment packages that had been attached to the outside of the docking compartment of the Mir space station. They also deployed the Spektr Solar Array Cap, designed to be used in a future Mir spacewalk to seal a leak in the Spektr module's damaged hull. Other tasks included evaluating tools and testing the Simplified Aid for EVA Rescue (SAFER).

But the beginning of that spacewalk was a little rocky.

"I was the lead spacewalker, and as I was moving out to begin the first task of the spacewalk I noticed that my safety tether wasn't retracting properly," Parazynski says. He tried to coax it back, but it wouldn't budge. "I tapped, pulled some more, locked and unlocked it. I had 15 feet of steel braid floating to my right." His first concern was that he or Titov could become tangled in the cable, or that it would get caught on a critical piece of hardware, but he also wanted to avoid being called back in without having

STS-131 and Expedition 23 crew members share a meal in the Unity node of the ISS while space shuttle Discovery remains docked with the station. Pictured are Russian cosmonauts Oleg Kotov, Expedition 23 commander; Mikhail Kornienko and Alexander Skvortsov, both Expedition 23 flight engineers; NASA astronauts Alan Poindexter, STS-131 commander; James P. Dutton Jr., STS-131 pilot; Clayton Anderson, STS-131 mission specialist; Tracy Caldwell Dyson and T.J. Creamer, both Expedition 23 flight engineers; Japan Aerospace Exploration Agency astronauts Soichi Noguchi, Expedition 23 flight engineer; and Naoko Yamazaki, STS-131 mission specialist.

accomplished the EVA objectives.

Having practiced the Russian tether protocol, Parazynski was equipped to use alternate means.

"I was able to continue the EVA using tools that I already had on my suit," he says. "I had to translate, or move, up and back between Mir and the shuttle, transferring payloads and other tools from place to place.

"We got the work finished completely and on time," he says. "It was a real source of pride."

Parazynski's most memorable spacewalk was his final one – during STS-120 in 2007. During that mission, the Harmony module was delivered to the ISS, opening up the capability for future international laboratories to be added to the station by connecting to Harmony. Another objective was relocating a solar array on the ISS, but during redeployment the array was damaged, and he was sent out to repair it.

"It was the fourth walk of that flight. The array had been hit by a micrometeroid. I had to go onto the ISS arm with a robotic boom." The task required that he travel approximately 90 feet, and that he remain out beyond the 45-minute maximum that is normally allowed for a one-way trip to a work site during EVA.

"The concern was that it would be too far from safety. But NASA stretched the rules due to the significance of the benefits." Not repairing the array would have resulted in there being insufficient power to supply the labs that are to connect to the ISS via Harmony.

"It was a challenge for Mission Control. Hundreds of people on the ground worked for three days to figure out how to get a spacewalker out there. I was working with 100 volts of energy coming through, and I had to take extra precautions to avoid shock."

What was going through his mind during this dangerous mission?

"I just didn't want to make any mistakes. It was very important, and the stakes were high. I didn't want to let people down."

In the end, the mission was a home run for NASA, he says, and one of the finest moments that the NASA team has ever had.

Downtime Up High

Jobs like that can be stressful, so downtime is scheduled into the astronauts' itineraries. In addition to a little free time each day, crews get a half-day off near the end of each flight. Parazynski's favorite memory comes from one of those half-days, during STS-66 in 1994, when he and French astronaut Jean-François Clervoy "invented a new sport, 3-D tennis." The two fabricated a ball out of duct tape and used two NASA procedures manuals as racquets, and played a few sets in a spacious mid-deck area out of harm's way. In other free times, he enjoyed photographing the spectacular views of Earth from the shuttle.

Mealtime is another period in which astronauts relax a little. During his shuttle missions to the ISS (STS-100 and STS-120) and Mir (STS-86), he enjoyed the camaraderie in the service modules with his U.S. and international colleagues.

"The service module is an interesting place. Everyone gathers around the table – there's music, laughter, sharing of food," he says. In the gravity-free environment, "pass the potatoes" becomes throw the potatoes." And while the foods – dehydrated and reconstituted – do not look appealing in most cases, he says that they are delicious, and that astronauts do look forward to eating. In fact, crewmembers often share food and hospitality, and as a result Parazynski had opportunities to sample international cuisines and cultures, particularly Russian.

"The Russians were very gracious hosts, and they brought good soups with them," he recalls.

Another treat was sweets."Chocolate is a huge thing," he says. An admitted chocoholic who always had some Oreos stashed onboard, he says the cookies made him "very popular" among his crewmates, who would invariably offer to trade other items to get a few.

Those little pieces of home mean a great deal, especially to long-duration astronauts on the ISS, who reportedly miss scents like freshly cut grass, pizza or their favorite foods. But shuttle astronauts are so busy, he says, there is not much time to be homesick, although it does happen.

"On my first flight, after we launched and were safe in orbit and had deployed a satellite, I got very homesick. I wanted to tell my family and friends what a great experience I was having. I felt very disassociated from home, and the communication was not very good in those early days." Now, astronauts keep in touch with loved ones, colleagues and the general public using technologies such as email, IP phones and Twitter.

All in all, Parazynski wouldn't trade his time in space for anything, and he says it changed him profoundly.

"It's a very awe-inspiring, humbling experience. I came back to Earth much more low key, with an incredible sense of peace and contentment. The little things that got under my skin didn't faze me after that experience. It also gave me a great sense of the beauty of the planet. From space, you see the fragility of the Earth, and you want to do what you can to preserve it."

Although he retired from NASA recently and is now Chief Medical Officer and Chief Technology Officer at the Methodist Hospital Research Institute, he says, "I'm a different person having had the gift of spaceflight." ■

Kathryn M. Duda is Assistant Manager of Public Affairs at the National Technology Transfer Center and Managing Editor of Technology Innovation.

For more information about Scott Parazynski's missions in space, visit www.jsc.nasa.gov/bios/htmlbios/parazyns.html or www.parazynski.com.

Please mention that you read about it in Technology Innovation.

A Natural Inventor

Former NASA Astronaut Scott Parazynski says, "I've always looked for better ways to do things, and tinkered with a variety of inventions in and around the space program and in medicine." One of his inventions accompanied him to the top of Mount Everest in 2009. Called the High Altitude Hydration System, the device keeps water in a liquid state under the most extreme conditions by using body heat, a small battery and thermal heater strips.

"I was highly motivated to stay hydrated on my way to and from Everest's summit," he says, "and this was a nice technical solution to the challenge."

During his time in space, Parazynski conducted research in a broad range of scientific disciplines. Experiments during his first mission involved global environmental monitoring and atmospheric spectroscopy. On subsequent missions he and his colleagues investigated topics in areas such as material science, life science, fluid physics, combustion physics and astrophysics. On STS-95 he was part of the team that tested the Hubble Space Telescope's cooling system.

The advent of the International Space Station's utilization phase means even more opportunities to conduct space-based research.

"The ISS National Lab is important to increase the access that researchers have to a microgravity environment," says Parazynski. "Taking gravity away as a variable allows scientists to study phenomena in an entirely new condition, looking at fundamental physical and life processes in unique ways."

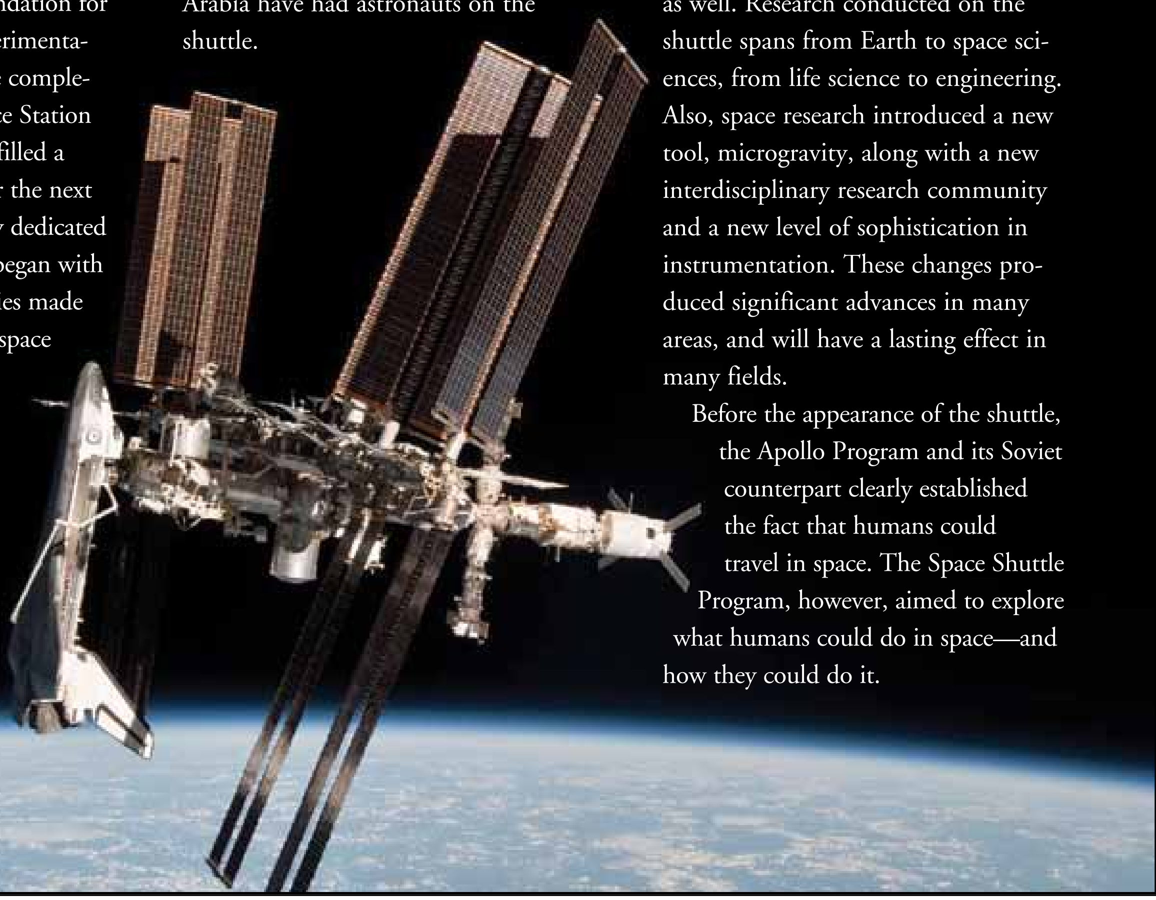
On a Flight to the Future

The Benefits of the Space Shuttle Program Beyond Retirement

By Bradley M. Carpenter, Ph.D.
NASA Headquarters

In the summer of 2011, 50 years after Yuri Gagarin first orbited the Earth, the Space Shuttle Atlantis made the 135th and final flight of the shuttle program. With that event, the thoughts of many reflect back on the iconic images and sounds of shuttle launches, and ahead as well, to a new era that the shuttle helped bring forth. The space shuttle has been at the heart of the American space program for the last 30 years. Since the first flight of Space Shuttle Columbia in April 1981, the shuttles have laid the foundation for a dynamic era of human experimentation and expansion. With the completion of the International Space Station (ISS), the shuttle fleet has fulfilled a large part of its mission. Over the next decade, the ISS will be largely dedicated to continuing the work that began with the shuttles, and the discoveries made will help to shape the role of space in the future.

From the beginning, the shuttle quickly became a bridge to space, not only for Americans, but for people in many countries partnering with the U.S. in space exploration. Beginning with the shuttle's second flight, which carried Canadarm – the mechanical arm built by the Canadian Space Agency, shuttle missions had international participation. In a cooperative effort between NASA and the European Space Agency (ESA), the second mission also carried an external research platform built by the ESA as part of its Spacelab program. The pressurized Spacelab laboratory module made its first flight on the ninth shuttle mission, after which 22 missions carried Spacelab modules or external platforms. Germany and Japan also sponsored research missions using the Spacelab pressurized module, and nations from Israel to Saudi Arabia have had astronauts on the shuttle.



The capability of the space shuttle to carry a crew of seven astronauts and large payloads enabled an amazing array of research activities to be conducted in space. It also represented a quantum leap in the number of Americans directly involved in the space program. Hundreds of scientists and thousands of high school and college students participated in projects that built and conducted experiments in space.

The international cooperation that began with the shuttle established relationships that continue today as part of daily life in on the ISS and will be essential in future exploration missions as well. Research conducted on the shuttle spans from Earth to space sciences, from life science to engineering. Also, space research introduced a new tool, microgravity, along with a new interdisciplinary research community and a new level of sophistication in instrumentation. These changes produced significant advances in many areas, and will have a lasting effect in many fields.

Before the appearance of the shuttle, the Apollo Program and its Soviet counterpart clearly established the fact that humans could travel in space. The Space Shuttle Program, however, aimed to explore what humans could do in space—and how they could do it.

Reimagining Spaceflight

Originally planned to serve as a "space truck," and to make space launches routine and utilitarian, the shuttle was not intended to be a technology development platform. With its requirements for reusability, delivery and return of payloads, and landing site flexibility, however, the shuttle emerged as a "reimagining" of spaceflight.

Capsule launches and reentries were fairly straightforward engineering, even if the reliability of the systems was not always high. In contrast, the shuttle was an airplane, and from an engineering perspective, totally new to spaceflight. There was a large margin of uncertainty regarding the control and dynamics of the integrated solid rockets and the main engines. Equally critical, the controlled reentry of a winged vehicle from orbit took the shuttle through flight regimes that had no previous experience or data.

In order to produce the first-of-its-kind space transportation system, NASA worked with numerous industry partners on a multitude of innovative technologies. For instance, in 1971, Rocketdyne started developing the space shuttle main engine under contract to NASA. A year later, the Agency contracted with North American Rockwell to build the orbiter. In 1973, NASA contracted with Martin Marietta (now Lockheed Martin) for the external propellant tank, with Morton Thiokol's Wasatch division for the shuttle's solid propellant rocket motors, and with United Space Boosters Inc. for the other components and assembly of the solid rocket boosters. The shuttle's external tank was built by Lockheed Martin Space Systems, and United Space Alliance prepared the orbiter for flight. As NASA and its partners worked toward a common goal, the space shuttle was born.

John Young and Robert Crippen, crew members on the first shuttle flight, STS-1, were test pilots in the truest sense. But it was a beautiful day at Edwards Air Force Base on April 14, 1981, when Columbia landed. A sea of spectators parked in the desert listened to "The Star-Spangled Banner" on local radio stations as they watched the shuttle return safely to Earth.

Benefits Brought Back to Earth

As a product of the Space Shuttle Program's fruitful partnerships to design, build, operate, and maintain the shuttle fleet, now NASA is moving ahead on a new path of innovation, driven by game-changing and crosscutting space technology programs. These programs will build on the accomplishments of the shuttle program and give rise to new ideas and capabilities. Already, many innovations have moved beyond NASA and into the public sphere.

For example, techniques developed for stabilizing the shaky video footage of the shuttle launches spun off to help the Federal Bureau of Investigation analyze video footage of the bombing at the 1996 Olympic Summer Games. Intergraph Government Solutions of Huntsville, Alabama, licensed the NASA technology and adapted it for the company's Video Analyst System, now used for military and law enforcement applications, including the capture of kidnappers and the identification of Saddam Hussein in footage sent back from Iraq.

In addition, a NASA engineer worked with Houston-based MicroMed Technology Inc., and the late renowned heart surgeon Michael DeBakey to develop a medical device based in part on space shuttle fuel pump technology. The MicroMed HeartAssist 5 ventricular assist device (VAD) functions as a "bridge to heart transplant," pumping blood to keep critically ill patients alive until a donor heart is available.

These examples represent just two of the ways the Space Shuttle Program has brought innovations back to Earth to benefit the public. In total, more than 120 different spinoff technologies have been attributed to the innovations made through the Space Shuttle Program. And even though the space shuttle era is closing, spinoffs like these will continue to save lives, support jobs, conserve energy and enhance national security. ■

Bradley M. Carpenter, Ph.D., works in the International Space Station office of the Human Exploration Operations Mission Directorate at NASA Headquarters. A fluid dynamicist, he was previously the Lead Scientist, and earlier the Fluid Physics Program Scientist, for the Microgravity Research Division.

For more information, contact Dr. Carpenter at bcarpenter@nasa.gov.

A retrospective account of the history and accomplishments of the Space Shuttle Program, written by those who worked in the program, is available at http://shopnasa.com/store/product/6604/-Wings-In-Orbit-Hard-Cover/.

Mission archives, multimedia content, and information about the Shuttle are available at the program home page: http://www.nasa.gov/mission_pages/shuttle/main/index.html.

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INNOVATION ALOFT

The ISS as an Orbiting Technology Demonstration

By Jason Crusan and
Benjy Neumann,
NASA Headquarters

Twenty-six expeditions.
Thirty-four space shuttle missions.
One-hundred-and-forty-six spacewalks.
Thirteen years of construction.

The assembly of the International Space Station (ISS) is truly massive in scope. With the delivery of the Permanent Multipurpose Module to the station by Space Shuttle Discovery during STS-133, the ISS is essentially complete. While this may imply that the station has not yet been utilized, that could not be further from the truth. Throughout the assembly process, the ISS has been serving as a technology and engineering demonstration, continuing to provide new insights into living and working in space, what future space travel will require, and what benefits space research and development can provide on Earth.

The ISS serves as a technology demonstration in three ways. As the most complex vehicle ever built, the ISS allows NASA and its partners to learn from the systems that operate onboard every day to sustain and operate it. Due to the long life cycle of the vehicle, it also provides the opportunity to hone methods for maintenance and operations. Finally, the ISS serves as a platform for NASA and its many partners to test and develop innovations with both space and terrestrial applications.

Learning from the ISS

The station's role as technology testbed platform is not new. One perspective that is sometimes overlooked, however, is the extent to which the vehicle's assembly, maintenance, and operations serve as a way to advance technology and management every day.

Throughout the first decade of the station's life, NASA has been collecting data on, and analyzing and sharpening systems of, the ISS itself. Many of its systems are the first of their kind to fly in space. For others, the long-term operations of systems allow scientists and engineers to understand how they perform over time in microgravity, enabling us to further advance those technologies. While many systems are viable during the design phase and short-term operations, the true test comes in balancing performance with the practical aspects of maintenance and reliability in the real operational environment of space.

> **"Increased performance in space, for example, usually means getting more out of less—more power, more breathable air, more consumable water—in order to ensure the health, safety, and performance of the ISS crew..."**

Increased performance in space, for example, usually means getting more out of less—more power, more breathable air, more consumable water—in order to ensure the health, safety, and performance of the ISS crew or to expand the capabilities of the station's research platforms. Balancing the need to increase the reliability of essential systems with the need to reduce reliance on consumables is critical to enabling longer-duration space missions. Today, NASA and its partners can provide spares to ISS in a reasonable amount of time; but obtaining replacement parts to repair the failure of a critical system on the surface of Mars would require months or years. Through the experience gained from the long-term operation of the ISS, extended missions like those to Mars move closer to reality.

Another way in which the ISS itself serves as an orbiting technology demonstration is through its essential life support systems. As it has done during the assembly phase, NASA will continue to advance one of the most critical elements of human space flight, the Environment Control and Life Support Systems (ECLSS). Among the ISS systems, the ECLSS is one of the most significantly challenging to develop and maintain, and it has the potential to be even more challenging in future space exploration missions.

ECLSS is made up of several complicated systems—all of which are seriously impacted by the microgravity environment. Because of this, in-space testing is critical to understanding their performance. The lessons and on-orbit operational experience is extremely valuable to NASA in planning for future systems. In addition, a number of components that help maintain the ISS as a habitable facility have been innovated by NASA's industry partners. The success of these components onboard the ISS has in many cases led to commercial versions of the technologies for providing essential needs from water purification and monitoring to air sanitization to communities on Earth.

The Vehicle Cabin Air Monitor (VCAM) provides a similar example. VCAM has as its core a gas chromatograph/mass spectrometer developed by NASA, with assistance from Houston-based Oceaneering International Inc. and Thorleaf Research Inc. of Santa Barbara, California. The team used the core technology that is widely found in chemistry labs but rarely used for spaceflight applications. A very sensitive instrument, VCAM has been tracking trace gases on the ISS at levels that are too low to harm the crew but that could gradually build up to dangerous levels.

"VCAM can not only identify what it was developed for, but by virtue of its design also has the ability to detect unanticipated contaminants," says Jitendra Joshi, Ph.D., chief technologist in the Advanced Capabilities Division of NASA's Exploration Systems Mission Directorate. "This real-time detection capability is extremely important in long-duration space missions."

Future missions could use a version of VCAM modified for extended life and water analysis capability.

Innovative Acquisition

The ISS also allows NASA and its partners to hone acquisition methods for maintenance and operations services. This is a somewhat unusual way of thinking about a testbed, but it is equally important to the future of space exploration.

In the Tranquility node aboard the International Space Station, NASA astronaut Doug Wheelock, Expedition 25 commander, works to install the new Sabatier system to extract more water out of the ISS atmosphere.

One of the great examples of innovative acquisition is with the Sabatier-based reaction system that supplies a water production service for the ISS. Sabatier-based reaction systems have been studied and developed for more than three decades—in fact, such a system had been planned for the ISS. Since the technology of the system was well understood, NASA was able to consider alternative acquisition models for the capability, and NASA's contractor, Hamilton Sundstrand, was willing to take on a new model for providing capabilities to NASA. Now part of the ISS's Water Recovery System, the technology can create up to 530 gallons of water annually for the ISS, drawing from byproducts of station's air supply systems.

While the NASA-Hamilton Sundstrand service contract is typical in many ways, it has an unusual twist: The company providing the service is paid only when the service is available. If there is an interruption in the service, the company is not paid. In return, the company can earn a higher return for taking on the additional performance risk of providing the service.

Although this was a contract, the nature of being closely integrated required both NASA and the company to treat the interaction as more of a partnership with clearly defined expectations and a good working relationship to get though the small hiccups that occur when paving such new ground.

An Ongoing Education

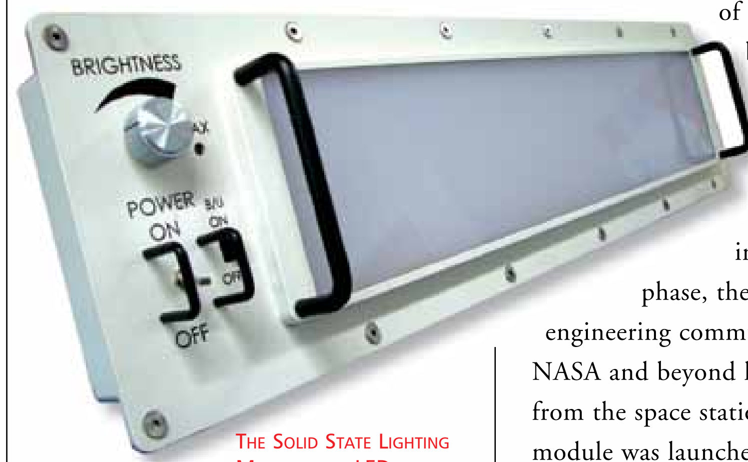
A number of platforms for technology demonstration exist in the current ISS program. However, with the 2010 NASA Authorization Act extending the station's operation through at least 2020, the Agency and the program should have additional opportunities to evolve key technologies and a decade-wide window in which to gain long-term experience on various technology platforms.

The ISS is a unique facility to test components, subsystems, and entire systems without having to invest in an entire mission. Additionally, the crew of the ISS tends to the experiments onboard the station, allowing them to take place in a shorter time frame and in an incremental experimental approach.

This fundamental capability, to serve as a platform for many experiments for NASA and its partners, is at the core of the station's advantages. In addition, the Authorization Act is enabling the full use of the ISS National Lab. This will allow private industry, academia, and other government agencies to take advantage of the unique environment of the ISS for their use.

Current examples of technologies being explored and developed through ISS testing by NASA and its partners include the Lab-on-a-Chip Applications Development Portable Test System (LOCAD PTS). Using technology developed by Wilmington, Massachusetts-based Charles River Laboratories International Inc., the LOCAD PTS can detect microbial threats to astronaut health, which will help NASA design contamination control strategies for the human exploration of Mars and other destinations.

Another example is a group of bowling-ball-size satellites called the Synchronized Position Hold Engage and Reorient Experimental Satellites, or SPHERES. Created by NASA, the Department of Defense, and the Massachusetts Institute of Technology, the devices are designed to test new guidance, navigation, and control capabilities for free-flying spacecraft. In addition, the Solid State Lighting Module was developed by Kennedy Space Center and is providing safer, energy-efficient LED lighting that could in the future be used as a passive treatment to help astronauts maintain overall health and wellness. A "spectrum engine" that emits little heat, is shatterproof, and does not contain toxic mercury, the LED lighting technology can produce wavelengths of light that stimulate health benefits, such as regulating the body's circadian clock, the natural sleeping and waking cycle.



The Solid State Lighting Module uses LEDs, which could help astronauts maintain health and wellness during missions.

These are only a few examples of the innovations being enabled by the ISS as a testbed facility. While the ISS is just entering its utilization phase, the scientific and engineering community within NASA and beyond has been learning from the space station since the first module was launched. With creative thinking about alternative methods to maintenance and operations and new ways to design experiments, the ISS will enable the next generation of exploration to new destinations. ■

The authors are in NASA's Human Exploration Operations Mission Directorate, where Jason Crusan is the directorate's chief technologist and Benjy Neumann is director of the Human Spaceflight Capabilities Division.

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WHY USE THE ISS FOR TECHNOLOGY DEVELOPMENT TESTING?

A Perspective from a NASA Business Partner

By Brian Rishikof
Innovative Space Propulsion Systems

The ISS provides a unique testbed with many advantages. First, the station is equipped with well-defined interfaces for all the necessary resources: power, data, mechanical, and analytical. This reduces the complexity, technical risk, and total cost for performing a technology development test.

For space applications, demonstrated effective operation in the space environment is essential for any new technology to be adopted. Given the criticality of flight heritage in maturing and commercializing technology for space, the ISS offers the shortest conceivable time-to-flight—about 18 months – for our project. The ISS's maturity and availability allows an aggressive schedule for in-space testing and demonstration, which allows businesses like ours to get to a marketable product sooner.

Innovative Space Propulsion Systems (ISP Systems) is developing a game-changing propulsion technology called NOFBX®, an environmentally safe, high performance monopropellant engine technology with improved safety and reduced costs. From a commercial perspective, it is clear from our discussions with many potential customers that the actual flight test in space changes the technology's potential from casual interest to true consideration for mission applications.

Invariably, the first question we are asked is, "Has it flown yet?" Our innovation has applications for commercial space flight, but ground testing will only achieve a technology readiness level (TRL) of 6 or 7—short of the "flight qualified" and "flight proven" qualifications necessary to bring the technology to market, especially in commercial applications.

Although behavior and performance can be well characterized on the ground, there are certain conditions that cannot be recreated but are required for our test objectives. Long-term exposure to the space environment, for example, cannot be simulated on the ground. A flight experiment like the one we plan to conduct on the ISS in 2012 will get us to TRL 8 or 9.

There are no other test platforms currently in existence or development on which a propulsion system of the scale we are working with can be flown and tested to meet all of our objectives in under two years. Employing the ISS as a test platform accelerates our schedule and significantly improves our business case and U.S. competitiveness.

But the advantages of the ISS as a technology development facilitator go beyond extended access to the space environment. The ability of the ISS to support video download and to provide generous mass, volume, and power capabilities allows us to rapidly design and fly a safety-compliant system for human spaceflight that can satisfy our thrust characterization, propellant transfer, and extended operations objectives in a single payload.

The applicability of this technology to crew vehicles (commercial or otherwise) is critical to several potential users. An ISS-based flight test forces our team, in a positive way, to comply with the NASA safety requirements associated with operation of our propulsion system at, or in the vicinity of, the ISS. This has proven to be important for potential customers who intend to perform operations at the ISS, using our propulsion system either as a replacement for existing implementation or for consideration as a cost-effective and safer baseline.

Throughout this process, engagement with the NASA ISS team provides access to independent expertise, processes, equipment, and experience. This adds significantly to the rigor of the work of our combined team and the confidence that the end product is ready to be safely used at the ISS, and by other customers for other applications.

Finally, the ISS provides unprecedented opportunity for domestic and international exposure, which can catalyze business opportunities and access to new markets. We are excited by the opportunity to fly next year. ■

Brian Rishikof is Vice President of Innovative Space Propulsion Systems LLC.

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"Lick and Stick" Sensor Systems Enhance Safety and Performance

By Gary. W. Hunter, Ph.D.
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Makel Engineering Inc.

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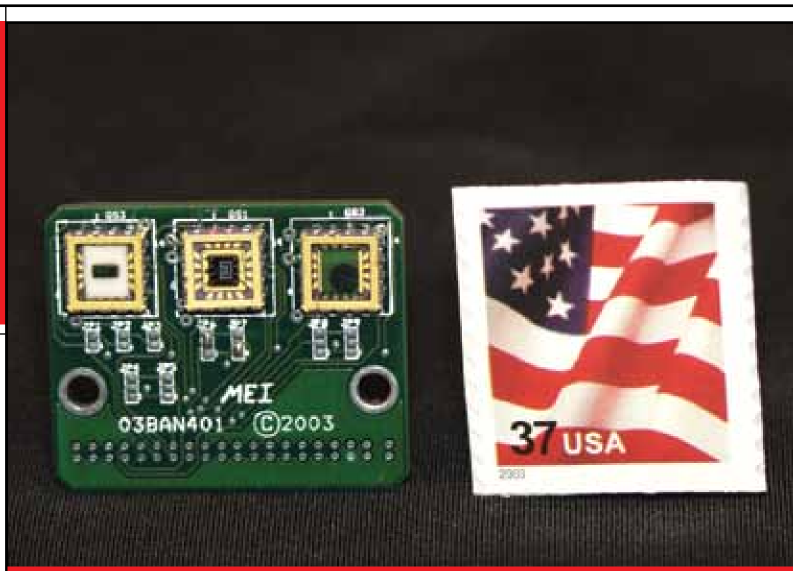
Case Western Reserve University



A "Lick and Stick" leak sensor system, developed by NASA with Makel Engineering and Case Western Reserve University, is an integral part of the ISS Advanced Life Support System.

In the aerospace industry, a leak in a pipeline or structure can be a life or death issue. A leak in a launch vehicle's fuel delivery system could, for example, lead to an explosion, damaging or destroying the vehicle and endangering the lives of workers and crew.

For this reason, NASA and its aerospace partners require the development of a range of chemical sensor technologies to increase safety, reduce emissions, and improve performance. In tandem with partners in industry and academia, NASA has improved propellant leak detection capabilities, resulting in a new sensor technology providing down-to-Earth benefits.

Through NASA's Small Business Technology Transfer (STTR) program, the Agency collaborated with Makel Engineering Inc. (MEI), headquartered in Chico, California, and Case Western Reserve University (CWRU) during the late 1990s to develop a microsensor system to meet NASA's need for leak detection technology. The partners employed microelecromechanical systems technology to produce small, lightweight sensors that use minimal power consumption—all ideal qualities for aerospace applications. This microfabrication approach also has been applied to other sensors to measure a range of chemicals and gasses, including hydrogen, hydrocarbons, nitrogen oxides, carbon monoxide, carbon dioxide, and oxygen. For each, the sensor structure and materials can be chosen to optimize detection of the target substance.

These sensors' small size allows them to form "smart" sensor systems—systems that can be adapted to a variety of tasks and conditions thanks to the incorporation of microprocessor technology. After years of development, additional STTR and Small Business Innovation Research (SBIR) program support, and further partnerships with NASA and The Ohio State University, MEI developed a range of smart gas sensor systems for a number of applications.

"Smart" Benefits

One such application is the "Lick and Stick" smart leak detection system, which includes hydrogen, oxygen, and hydrocarbon sensors to allow measurement of both fuel and oxygen using a stand-alone leak detection system that can be applied wherever and whenever necessary (hence the "Lick and Stick" nickname). The technology can be configured for wired or multiple wireless configurations, to be battery powered, or to accommodate a range of sensor technologies.

The core smart sensor technology is now an integral part of the Advanced Life Support Systems on the International Space Station (ISS). The sensors monitor hydrogen levels in the ISS' oxygen regeneration system, providing warnings well in advance of hydrogen concentrations reaching explosive levels in the oxygen lines—an obvious safety feature for the

In addition to its use onboard the ISS, the Smart Leak Sensor System developed at NASA has provided monitoring for the hydrogen-powered Ford U concept car.

crew onboard the station.

Use on the ISS is but one of many applications of the core smart sensor technology—each with its own unique requirements. For NASA, the smart leak detection system has been demonstrated or applied on the space shuttle and the experimental Helios vehicle. Outside of the Agency, the sensor innovation has provided monitoring for the hydrogen-powered Ford U concept car.

"Our partnership with NASA in the development of the lick-and-stick technology has resulted in a wide range of sensor and smart systems products, which have generated a large percentage of company revenues and supported multiple engineering jobs," says Benjamin J. Ward, Ph.D., of Makel Engineering. "The lick-and-stick technology and the products that have spiraled from it are used in our leak detection, turbine emissions monitoring, fluid sensing, and other smart systems."

Beyond leak detection, these systems have been demonstrated or applied for everything from measuring jet engine emissions to detecting aircraft fires. The technology enables a smart fire detection system for use in the cargo bays of aircraft and future exploration vehicles, where the basic lick and stick hardware is integrated with sensors for fire detection. The systems also enhance safety for rocket engine teststands and provide a powerful tool for environmental observation and even human health applications like breath monitoring.

NASA's hydrogen sensor hardware configurations were used for demonstration on the space shuttle.

Innovation with a Vision

So far, this NASA partnership-derived, microsensor-based technology has been recognized with several awards, including two "R&D 100" Awards (indicating the innovation was one of the 100 most significant inventions and products of the year), two NASA "Turning Goals into Reality Awards," and a nomination for NASA "Invention of the Year." Further advancements of this core technology have been funded by organizations including the U.S. Navy, Air Force, and Army; the State of Ohio; and the Department of Energy.

The long-term vision for the technology is to implement the systems wherever and whenever the technology is needed, allowing users to make decisions that will increase safety, reduce emissions, and improve performance within the aerospace industry and beyond. ■

Gary Hunter, Ph.D., is the Technical Lead for the Chemical Species Gas Sensors team, and Lead for Intelligent System Hardware in the Sensors and Electronics Branch, based at NASA Glenn Research Center. Chung Chung-Chiun Liu, Ph.D., is a Professor of Chemical Engineering at Case Western Reserve University. Benjamin J. Ward, Ph.D., is a Senior Engineer at Makel Engineering Inc.

For more information, contact Dr. Hunter at gary.w.hunter@nasa.gov, or visit www.grc.nasa.gov/www/chemsensors/

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Technologies are available for licensing and joint development at each of the NASA Field Centers through their Innovative Partnerships Offices. Provided here are details on a sampling of numerous available technologies. Read more about other new technologies each month in NASA TechBriefs (www.techbriefs.com), and for a comprehensive list, go to www.technology.nasa.gov.

Nondestructive Inspection and Evaluation of Corrosion Under Paint

Painted steel and aluminum structures can cost NASA centers millions of dollars per year in maintenance costs. Because paint can obscure corrosion, sandblasting of the protected surfaces is required to check for deterioration. After sandblasting, however, there is often little to no corrosion found, and the sandblasted structure must be repainted. This is especially problematic for launch towers, bridges, painted aluminum structures, and other steel structures.

To detect corrosion under paint on steel and aluminum without having to remove the paint or other surface materials, NASA Kennedy Space Center engineers developed a new nondestructive evaluation and inspection technique based on millimeter-wavelength scanning signals. The device operates by scanning a painted metallic surface and using two signals simultaneously to sense the presence of passive intermodulation products—undesirable new signals generated when frequencies are mixed. A dielectric lens antenna focuses energy onto a one-inch-diameter spot, increasing the incident millimeter wave power levels to the point of producing passive intermodulation products when corrosion is present.

Kennedy Space Center's new nondestructive evaluation/inspection technique can save time and money in determining when painted structures need to be sandblasted or cleaned.

Components of the device include two frequency sources that produce two signals set to the same general microwave band, but at slightly separated frequencies. The two signals are combined in a two-way power combiner and fed through a four-port, two-way direction coupler into the dielectric lens antenna aimed at the metal surface. Tested in a laboratory environment, the technology is capable of detecting corrosion over areas smaller than 0.25 square inches through paint or thermal protection material from 0.008–12 inches thick.

Lower Maintenance, Energy Costs

If the technology is fully developed, it may be possible to reduce maintenance costs by using the instrument to determine when painted structures need to be sandblasted or otherwise cleaned and repainted on a longer recurring schedule than presently used. The device inspects at a rate of 15 seconds per square inch, with fewer false positives compared to current commercial units, and uses less than 5 Watts of power. In production quantities, the costs are expected to be in the $30,000 range.

The technology is ideal for detecting corrosion in steel and aluminum materials, large structures, and pipeline-type structures, including cryogenic lines. Applications for the innovation include Navy and commercial cruise ships; airplanes and aerospace vehicles; communication towers, bridges, and tunnels; tanks, water towers and other containers; and insulated pipelines.

Kennedy is currently seeking partners interested in the commercial application of the nondestructive inspection and evaluation of corrosion under paint technology. The Agency has already applied for a U.S. patent, and is now seeking licensees. Individually negotiated, each NASA license contains terms concerning commercialization, license duration, royalties, and periodic reporting. These patent licenses may be exclusive, partially exclusive, or nonexclusive. ■

For more information and details about licensing this technology, please contact Jeff Kohler at (321) 861-7158, or jeffrey.a.kohler@nasa.gov. Please reference case number KSC-13480.

Please mention that you read about it in Technology Innovation.

ShuttleSCAN 3-D: High-Speed Three-Dimensional Laser Scanner with Real-Time Processing

A 3-D surface scanning and profiling technology originally developed for critical, real-time inspection of damage to the thermal protection tiles of the space shuttle is available for a wide range of commercial applications from product quality control to autonomous navigation. Powered by the onboard Surface Profiling and Characterization Engine (SPACE) processor, the patented ShuttleSCAN provides real-time analysis of surfaces ranging from the small (such as circuit boards) to the large (such as panels or roads).

The ShuttleSCAN 3-D surface scanning and profiling technology has applications related to aerospace, the automotive industry, pipeline inspection and industrial machine parts.

Developed by NASA Ames Research Center, the scanner's operation is based on the principle of Laser Triangulation. The ShuttleSCAN contains an imaging sensor; two lasers mounted on opposite sides of the imaging sensor; and a customized, on-board processor for processing the data from the imaging sensor. The lasers are oriented at a given angle and surface height based on the size of objects being examined. For inspecting small details, a scanner is positioned close to the surface. This creates a small field of view but with very high resolution. For scanning larger objects, a scanner can be positioned several feet above the surface. This increases the field of view but results in slightly lower resolution.

The laser projects a line on the surface, directly below the imaging sensor. For a perfectly flat surface, this projected line will be straight. As the ShuttleSCAN head moves over the surface, defects or irregularities above and below the surface will cause the line to deviate from perfectly straight. The SPACE processor's proprietary algorithms interpret these deviations in real time and build a representation of the defect that is then transmitted to an attached PC for triangulation and 3-D display or printing. Real-time volume calculation of the defect is a capability unique to the ShuttleSCAN system.

Fast and Versatile

ShuttleSCAN creates more than 600,000 3-D points/second—among the highest available, and in real time from the integrated SPACE processor. Able to scan areas from square centimeters to square meters, the technology is extremely versatile, detecting details smaller than .001 inch (with smallest field of view architecture). It is also wireless and small, offering 802.11G wireless or Gigabit Ethernet wired connectivity, and at 7.25 x 5.5 x 5.4-inches, weighs only 2.9 pounds.

The scanner can be applied to many uses, including inspection of aircraft and spacecraft fuselage surfaces, autonomous navigation by mobile robots, inspection of pipelines for corrosion-related defects, optical 3-D scanning of printed circuit boards for inspection and positioning, scanning reusable metal hardware sealing surfaces to detect flaws that would impact sealing ability, scanning industrial machined parts for dimensional accuracy, and road surface profiling. ■

For more information and details about licensing this technology, please contact Phil Herlth at philip.m.herlth@nasa.gov. Please reference Case Number ARC-14652/15057.

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The Common Extensible Cryogenic Engine (CECE) shown here is fueled by a mixture of -297 degree Fahrenheit liquid oxygen and -423 Fahrenheit liquid hydrogen. Measuring such liquids in cryogenic tanks requires special instruments, such as the Cryogenic and Non-Cryogenic Optical Liquid Level Instrument for Stratified Conditions available for license from NASA's Marshall Space Flight Center.

Cryogenic and Non-Cryogenic Optical Liquid Level Instrument for Stratified Conditions

When NASA scientists needed a way to quickly determine the amount of cryogenic liquid being used in rocket engine testing, they developed a highly accurate, versatile liquid level metering technology to perform the task. Such measurements can be especially difficult to obtain because the systems usually involve constant mixing between gaseous and liquid states, and can lead to turbulent flow, cavitation, and sloshing.

Innovators at NASA Marshall Space Flight Center developed the unique prototype to precisely measure liquid levels to 0.1 percent of the sensor length with gigahertz data acquisition rates. Employing a novel process, the device is faster and more accurate than typical cryogenic liquid metering methods and enables measurements of rapidly changing fluid levels or sloshing liquids. In addition, other cryogenic metering systems register the thermal change between liquid and gas fluid phases, which limits accuracy in cryogenic conditions.

(continued on page 58)

INDUSTRY PARTNERSHIPS WITH NASA

Introducing Robonaut2

By Jason Crusan and Benjy Neumann,
NASA Headquarters

Robonaut2 surpasses previous dexterous humanoid robots in strength.

You may have seen it in a special appearance on the pregame show before the 2011 Super Bowl. Perhaps you spotted it shaking hands with lawmakers in the U.S. Capitol Visitor Center, or lifting weights with NASA Administrator Charles Bolden. Now crew members onboard the International Space Station (ISS) have met their newest colleague, Robonaut 2, or R2, the humanoid robot created by NASA and General Motors to work alongside humans, whether astronauts in space or workers in manufacturing plants on Earth. With a destiny to become the first permanent resident on the International Space Station, R2 launched on Space Shuttle Discovery in February 24, 2011.

Engineers and scientists from NASA and General Motors (GM) worked together through a Space Act Agreement with Johnson Space Center to build the 300-pound robotic assistant. Unpacked on the ISS on March 15, R2 consists only of a head and upper body. On its current mission, R2 is configured to work in a semi-stationary mode, anchored to a location on the ISS. From this position, its torso, arms, and hands can move freely, allowing its operators to test the robot's ability to manipulate objects on a task board populated with interfaces typically used by the space station's human crew. Lessons learned from the first year of operations will allow R2's team to gain experience handling the interfaces in microgravity. By using R2 on the ISS, modifications to software can be uploaded and hardware can be improved and advanced incrementally, saving the time and costs involved with flying the robot on multiple missions.

Designed with the dexterity to handle human tools and work side-by-side as an assistant to humans, the use of R2 should enable the completion of more complex tasks, possibly hazardous tasks, or tasks that require longer preparation. For example, R2 can work around the clock preparing a worksite in space in order to maximize the time a human spends in extra-vehicular activity performing tasks that require judgment and reason. This could potentially provide for greater efficiency on future missions, as well as reduce human exposure to safety risks in the harsh environment of space.

Robonaut2 was designed through a joint venture between NASA and General Motors to assist astronauts in space and workers at manufacturing plants.

While R2 may soon help make life onboard the ISS easier and safer, the advances in robotics made through the NASA-GM partnership promise to provide similar contributions on Earth. According to Alan Taub, GM's Vice President for Global Research and Development, the benefits of R2 on Earth include safer cars and safer manufacturing plants.

"When it comes to future vehicles, the advancements in controls, sensors, and vision technology can be used to develop advanced vehicle safety systems," he says. "The partnership's vision is to explore advanced robots working together in harmony with people, building better, higher quality vehicles in a safer, more competitive manufacturing environment."

While the concept of a Robonaut has been around for a long time, direct humanoid systems designed to work with astronauts is a first. The sensors, control software, robot vision, and other technologies emerging from the Robonaut program are representative of the unprecedented innovation that often results from NASA partnerships.

"This cutting-edge robotics technology holds great promise, not only for NASA, but also for the Nation," says Doug Cooke, Deputy Associate Administrator for NASA's Human Exploration and Operations Mission Directorate. "I'm very excited about the new opportunities for human and robotic exploration these versatile robots provide across a wide range of applications." ■

The authors are in NASA's Human Exploration Operations Mission Directorate, where Jason Crusan is the directorate's chief technologist and Benjy Neumann is director of the Human Spaceflight Capabilities Division.

For more information contact Crusan at jason.crusan@nasa.gov

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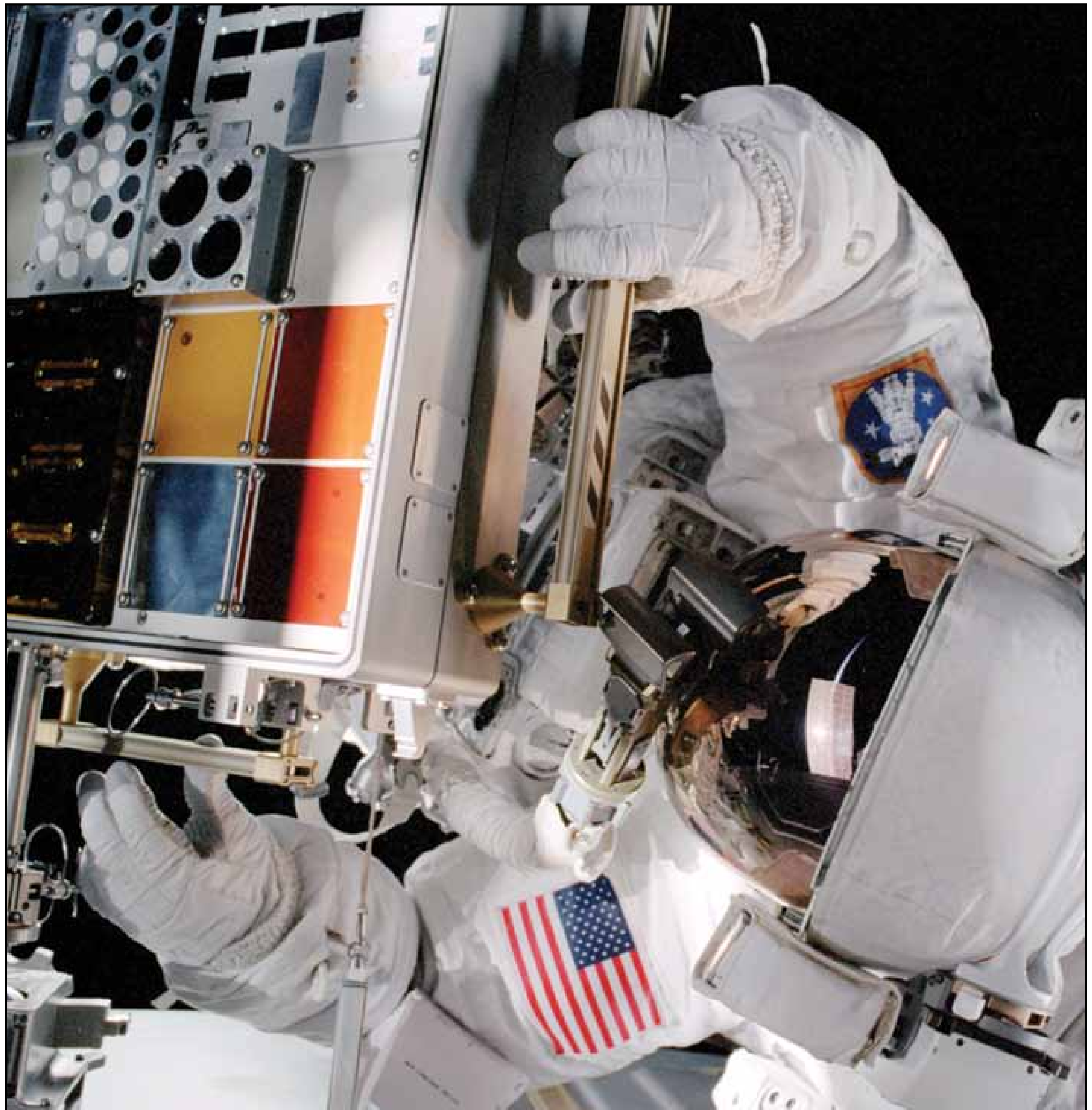
Tough Enough for Space

Testing Spacecraft Materials on the ISS



Materials International Space Station Experiment (MISSE) studies the environmental durability of materials and components in low-Earth orbit. Participants from NASA, DoD, industry and academia have tested materials since the experiments began in 2001.

By Kim K. de Groh and
Donald A. Jaworske, Ph.D.
NASA Glenn Research Center

William H. Kinard
NASA Langley Research Center
(Retired)

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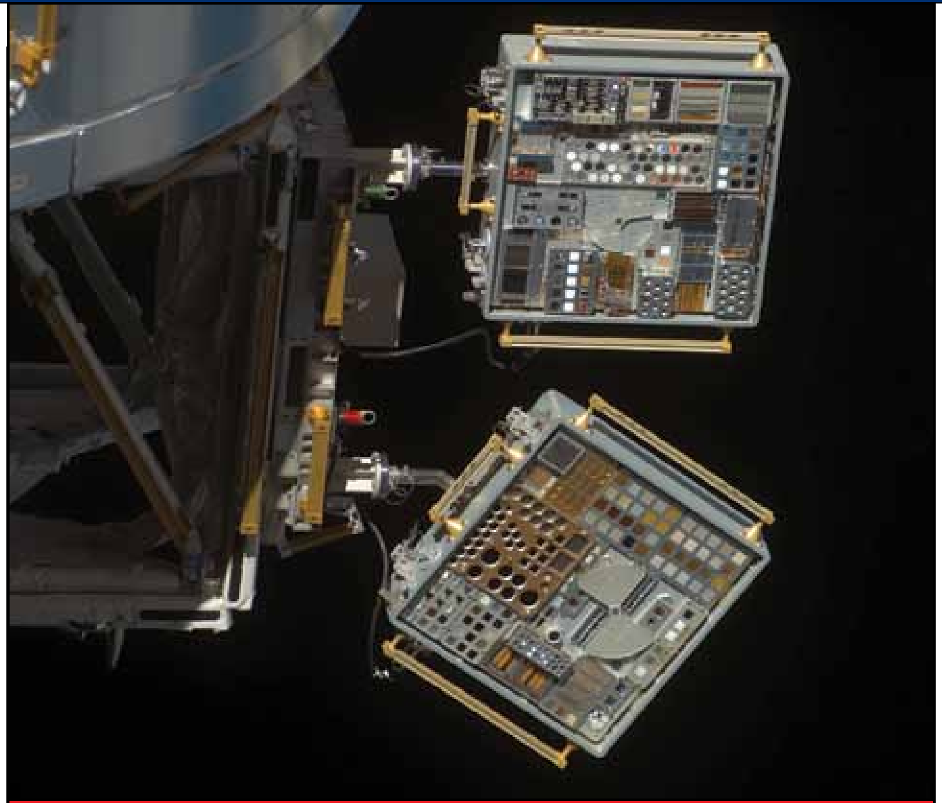
Boeing Research and Technology
(Retired)

Phillip P. Jenkins M.S.E.E.
Naval Research Laboratory

Homeowners know that exposure to the elements exacts a toll on a property. Paint bleaches and chips, wood warps and cracks, fixtures tarnish. Weather, temperature changes, and the sun's rays combine to wear things down.

Spacecraft have to deal with a much more extreme set of circumstances: unfiltered solar and cosmic radiation, temperatures fluctuating hundreds of degrees, impacts from micrometeoroids and orbital debris—even the nasty effects of atomic oxygen, which severely corrodes many plastics and metals. These factors combine within the vacuum of space, which affects the physical qualities of many materials, to create an environment that is extremely abusive to a spacecraft's exterior.

Determining how long-term exposure to space conditions impacts various materials—and thus which materials are best suited for spacecraft construction—can most effectively be accomplished through testing in space. NASA has conducted experiments evaluating the environmental durability of various materials, devices and components in space since the early 1970s, including the Long Duration Exposure Facility, which was retrieved in 1990 after spending 68 months in low Earth orbit. Over the past decade, one such ongoing experiment series has brought NASA and various partners together in an effort that is promising significant returns.



MISSE 6A and 6B Passive Experiment Container, shown on the European Research Laboratory Columbus, was photographed during a flyaround of STS-123 Space Shuttle Endeavor.

Introducing MISSE

The Materials International Space Station Experiment (MISSE) is a series of materials flight experiments, the first two of which were delivered to the International Space Station (ISS) during STS-105 in 2001. Much like how paint manufacturers test samples on Earth by exposing them to the Sun and weather for extended periods, the overall objective of MISSE is to test the stability and durability of materials and devices in space in order to gain valuable knowledge on their performance, as well as to enable lifetime predictions of new materials and components that may be used in future spaceflight. Consisting of a pair of trays hinged together like a suitcase called a Passive Experiment Container (PEC), and containing an array of samples, the experiment is attached to the exterior of the ISS, providing long-duration exposure to space conditions. After one or more years, astronauts retrieve the PECs and return them to Earth for study.

MISSE was originally conceived at NASA's Langley Research Center

GOVERNMENT AGENCY PARTNERSHIPS WITH NASA

as a way to gain valuable extended use of the PECs first flown on the Mir Environmental Effects Payload as part of the Shuttle-Mir program in the mid-1990s. To develop the project, Langley partnered with Boeing, which recruited other organizations to participate on the original MISSE experiment team. The Air Force Research Laboratory-Wright Labs/Materials Laboratory (AFRL/ML) also was key to the project development, providing funding support and Space Experiments Review Board (SERB) approval for flight. Other NASA centers, Department of Defense (DoD) organizations, and various aerospace companies have joined the project over the first decade of MISSE activities, and the number is now approaching 100.

To date, all of the planned 10 PECs (and one smaller tray) have been flown, representing MISSE 1 through MISSE 8. While the project has a fairly basic foundation (expose materials to space for awhile, then characterize the samples post-flight to see what happened), MISSE has evolved significantly over the years. While MISSE 1–4 contained primarily "passive" experiments, MISSE 5 included "active" experiments that were battery powered and included telemetry to the ground via radio. MISSE 6 and 7 were both expanded to accommodate a growing number of organizations that wanted to fly new experiments, and both contained active experiments powered directly from the ISS.

In MISSE 2, the Polymer Erosion and Contamination Experiment tray is shown after nearly four years of exposure to the space environment.

Materials flown on MISSE have included polymers, ceramics, composites, coatings, adhesives, and foams. The experiment has tested materials for various specialized applications such as radiation shields, inflatables, markers, labels, and optics. Components flown have included switches, sensors, solar cells, semiconductors, mirrors, optical devices, and tethers. MISSE has even included biological specimens, such as spores, bacteria, and millions of basil seeds later distributed to students to encourage interest in science.

Benefits for NASA and Partners Alike

With participants from NASA, DoD, industry, and academia, MISSE is currently the longest running multi-organization technology, development, and materials testing project on the ISS—producing many tangible benefits for the Agency and its partners.

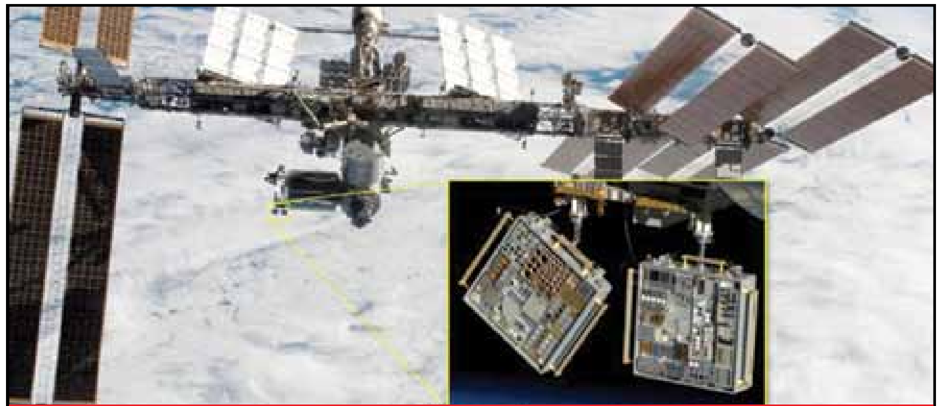
Providing rapid access to space, MISSE has yielded mission-critical solar cell performance data for groups such the Naval Research Laboratory, enabling DoD mission hardware to be designed and built in a timely manner. Shane B. Juhl, AFRL engineer and MISSE program manager at the AFRL, says, "the AFRL has seen significant outcomes from MISSE, from new, higher-power solar cell technology and electromagnetic shielding nanomaterials, to fundamental science knowledge and improved understanding of combined space effects on materials and devices."

Chicago-based Boeing has used MISSE for space radiation dose measurements, and Iwona A. Palusinski, associate systems director at The Aerospace Corporation of El Segundo, California, says, "The Aerospace Corporation, has found that MISSE experiments reduce the risk of incorporating new technology into future satellite systems, providing an inexpensive way to evaluate space readiness on a small scale."

Many MISSE investigators use MISSE flight data to compare on-orbit results with ground-based testing to improve techniques for modeling the behavior and performance of materials in space.

For NASA, the MISSE experiments have had a direct impact on numerous space programs, such as the Hubble Space Telescope, the Commercial Orbital Transportation System (COTS), and the ISS. MISSE has also provided quality data on the problem of corrosive atomic oxygen. The data have been used to develop a predictive tool for new and non-flown polymers and to enable more accurate durability predictions to be made based on ground-laboratory testing—meaning future materials may be better suited to withstand the atomic oxygen found in low Earth orbit.

MISSE has provided educational opportunities in science and engineering, as well. As part of MISSE, Glenn Research Center conducted experiments in collaboration with students from Hathaway Brown School in Shaker Heights, Ohio. The students have authored research papers, presented their work at international conferences, and entered their research in science fairs, winning more than $80,000 in scholarships and awards. Overall, the number of presentations, papers, and technical reports derived from MISSE data already exceeds 200, offering researchers around the world the benefit of the valuable performance and durability data being collected in space.



The ISS with a MISSE experiment attached to its exterior. Inset shows the various materials exposed to the space environment.

An Economical Approach to Critical Research

MISSE flight data have been widely requested by various NASA field centers, as well as numerous aerospace organizations and innovative companies, directly impacting design choices in spacecraft materials for satellites. To date, approximately $50 million has been expended by participants directly in support of the first seven MISSE packages.

Based on information gained from about 25 percent of the experiments flown, estimates of the return-on-investment on direct benefits from MISSE range from $150 million to $600 million, meaning this simple, practical, yet innovative approach to space materials testing—enabled by NASA partnerships—is promising big economic value on top of the benefits it is already providing.

MISSE 8, delivered to the ISS in May 2011 during STS-134, is planned for return on a SpaceX vehicle, Commercial Resupply Service flight, CRS-5, scheduled for launch in February 2013. ■

Kim K. de Groh is a Senior Materials Research Engineer at NASA Glenn Research Center. She is the principal investigator for the MISSE Science project at NASA Glenn and for 13 MISSE experiments.

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William H. Kinard, retired from NASA, was principal investigator for the Long Duration Exposure Facility. He received the NASA Medal for Exceptional Scientific Achievement and the NASA Distinguished Service Medal.

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Please mention that you read about it in Technology Innovation.

Opportunities in Orbit: A New National Lab

By Marybeth A. Edeen
NASA Johnson Space Center

The age-old saying goes, "When one door closes, another one opens." The designation of the International Space Station (ISS) as a National Lab is just one example of the many doors beginning to open after the retirement of the Space Shuttle Program.

In this case, NASA has opened the doors (or perhaps hatches) of the ISS to U.S. government agencies, academic institutions, and private firms for basic and applied research and technology development to benefit the American public.

Currently, the National Institutes of Health, Department of Defense, Department of Agriculture, Department of Energy, and National Science Foundation all have agreements with NASA to perform research on the ISS. The studies span human health to particle physics to technology development.

Work in Progress

Numerous universities and private firms have already taken advantage of this opportunity, and a variety of projects are in various stages of discussion and execution. One of these is research under the National Lab Pathfinder initiative, an effort to demonstrate the benefits of spaceflight for non-NASA related research. BioServe Space Technologies at the University of Colorado in Boulder is working with Austin, Texas-based Astrogenetix, a wholly owned subsidiary of Astrotech International, to develop vaccines for bacterial pathogens. Research on *Salmonella*-induced food poisoning and methicillin-resistant *Staphylococcus* will soon lead to applications for investigational new drugs with the Food and Drug Administration. Along with the University of Florida Tropical Research and Education Center based in Homestead, Florida, Bioserve is working to improve select plant groups to produce oil for biofuels.

Conducting research to enable further space-based discoveries, Ad Astra Rocket Company of Webster, Texas, is developing a payload to demonstrate a new kind of propulsion innovation called Variable Specific Impulse Magnetoplasma Rocket technology, which could be used for space travel outside of low Earth orbit. In addition, Houston, Texas-based NanoRacks LLC developed a platform that serves as an interface for standard nanoscale payloads, which will pave the way for future research and educational payloads in numerous fields, and Louisiana State University is building on previous research into the behavior of mixable fluids in microgravity—work that will contribute to materials processing and fluid handling in weightlessness. To allow researchers to use their own lab control systems to conduct experiments onboard the ISS, Chicago-based Boeing Aerospace has developed and tested a proof-of-concept software interface system.

For the pursuit of knowledge about how space makes a difference in our daily lives, Microsoft Corporation of Redmond, Washington, conducted an educational competition for high-school students to develop Web pages related to ISS and benefits to the public, while The LEGO Group, headquartered in Billund, Denmark, is developing kits to run competitions and perform educational outreach activities that demonstrate the physics of microgravity for elementary and middle-school students.

Opportunity Knocks

Currently, NASA is awarding opportunities for academic institutions and private firms to perform research on the ISS through two mechanisms. The first is under an announcement titled "Opportunity for the Use of the International Space Station by Domestic Entities Other Than U.S. Federal Government Agencies." Under this announcement, academic institutions or private firms can propose research or technology development work on the ISS that is completely self-funded. Proposals are evaluated based on the approach, benefit to the public and financial commitment. If approved, the proposer is awarded a Space Act Agreement (SAA), which allows NASA to provide payload physical, analytical, and operations integration to the awardee, and the awardee receives the opportunity to perform research on the ISS. No funding is provided to the proposer under this announcement.

The second mechanism is the "Broad Agency Announcement Enabling Support Equipment and Services for ISS as a National Lab." This allows proposals under the categories of payload integration and operations support services, as well as support equipment and services. Payload integration and operations support services covers advanced payload integration systems to enable utilization for a broad range of research and technology development and project specific payload integration and operations support. Support equipment and instrumentation provide opportunities for proposals that advance the capabilities of the ISS for utilization. Proposals received under the Broad Agency Announcement are evaluated based on relevance to the National Lab, overall scientific and technical merit, potential contribution to the National Lab, program management, and cost realism. Cost sharing and matching are strongly encouraged. If chosen, the proposer can be awarded an SAA, a contract, a grant or a cooperative agreement, depending on the scope of the proposal and available funding.

NASA astronaut Piers Sellers works with Group Activation Packs (GAPs) on the middeck of Space Shuttle Atlantis while docked with the ISS. GAPs are manufactured by BioServe Space Technologies and used to culture bacteria in orbit as part of the National Lab program.

"Having a permanent laboratory in low-Earth orbit, with cutting-edge research hardware and a trained crew offers industry a quantum leap forward in unimagined opportunities," says Jeffrey Manber, managing director of NanoRacks. "Companies in a wide range of disciplines, from bio-pharmaceutical research to nano-technology to sensors and optics will be users of this fantastic research facility," he continues.

These opportunities represent a real means to connecting innovators on the ground with the unique research facility that is the ISS National Laboratory, thus providing a path to discoveries and solutions that—literally—cannot be found on Earth. ■

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For details on these opportunities and the agreements with other government agencies, and to see the types of award that have been made, please visit http://www.nasa.gov/mission_pages/station/research/nlab/index.html.

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The Cryogenic and Non-Cryogenic Optical Liquid Level Instrument for Stratified Conditions has applications in aerospace, automotive, aviation, and foods and pharmaceuticals. For more information on licensing this technology, contact Marshall Space Flight Center.

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A Simple and Inexpensive Approach

While other sensors that measure liquid levels in tanks require complicated tank modifications and detection instruments, which increases costs and complexity, the NASA technology is simpler and less expensive. It can be incorporated directly into a plastic tank, and in some applications, eliminate the need for holes in the tank. As a flexible instrument, the technology accommodates snaking through access ports or shaping to fit tank contours. It also avoids an explosion hazard, as it requires no electrical signals in the tank.

This cryogenic and non-cryogenic optical liquid level instrument for stratified conditions is currently available for licensing from NASA for commercial applications. Applicable in a wide range of environments, including high and low temperatures and pressures, and in corrosive environments, the technology is ideal for cryogenic and non-cryogenic ground tank metering applications, as well as zero-gravity systems that include stratification or settling techniques.

Aside from the aerospace industry's applications for rocket propulsion testing, engine fuel tanks, and cryogenic tanks, it is applicable in the automotive industry for liquid hydrogen fuel tanks, petroleum, gasoline, and liquid natural gas tanks. It is also applicable in the foods and pharmaceuticals industry for high temperature, contamination-free storage and transportation, as well as in aviation for jet engine fuel tanks. ■

For more information and details about licensing this technology, please Sammy Nabors at (256) 544-5226, or sammy.nabors@nasa.gov. Please reference case number MFS-32642-1.

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